APPENDIX A

QUALITY ASSURANCE PROJECT PLAN (QAPP)

Integrated Watershed Approach Demonstration Project (Phase 1) for the Green Bay AOC/Lower Fox River Watershed

Quality Assurance Project Plan

Task Order No. 2006-23

Prepared for:

U.S. Environmental Protection Agency Region 5
77 West Jackson Boulevard
Chicago, IL 60604-3507

Prepared by:

The Cadmus Group, Inc.
57 Water Street
Watertown, MA 02472

USEPA Contract Number 68-C-02-109

December 29, 2006
Revision 1

This quality assurance project plan (QAPP) has been prepared according to guidance provided in *EPA Requirements for Quality Assurance Project Plans* (EPA QA/R-5, EPA/240/B-01/003, U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC, March 2001) and *EPA Guidance for Quality Assurance Project Plans for Modeling* (EPA QA/G-5M, EPA/240/R-02/007, U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC, December 2002) to ensure that environmental and related data collected, compiled, and/or generated for this project are complete, accurate, and of the type, quantity, and quality required for their intended use. The Cadmus Group, Inc. will conduct work in conformance with the quality assurance program described in the procedures detailed in this QAPP.

Section A – Project Management

A1 Approval Page

1/23/07		1/23/07	
Laura Blake Project Manager The Cadmus Group, Inc.	Date	Dr. Julie Blue Quality Assurance Officer The Cadmus Group, Inc.	Date
1/22/07		1/22/07	
Paul Baumgart Project Manager UWGB	Date	Daniel Bounds P.E. Senior Project Manager CDM	Date
1/24/07		1/24/07	
Dean Maraldo Contracting Officer's Representative U.S. EPA Region 5	Date	Simon Manoyan QA Officer U.S. EPA Region 5	Date
1·24·07		1·24·07	
Kevin Pierard, Chief Watersheds and Wetlands Branch U.S. EPA Region 5	Date	Jo-Lynn Traub, Director Water Division U.S. EPA Region 5	Date

A2 Table of Contents

Acronyms and Abbreviations

AOC	Area of Concern
AWC	Available Water Capacity
BMP	Best Management Practice
CDM	Camp, Dresser, and McKee Inc.
CN	Curve Number
CWA	Clean Water Act
EPA	U.S. Environmental Protection Agency
GBMSD	Green Bay Metropolitan Sewerage District
GIS	Geographic Information System
IWA	Integrated Watershed Approach
LFR	Lower Fox River
LFRWMP	Lower Fox River Watershed Monitoring Program
NPS	Nonpoint Source
NWS	National Weather Services
NRCS	Natural Resource Conservation Service
O&M	Operation and Maintenance
QAPP	Quality Assurance Project Plan
SS	Suspended Sediment
SWAT	Soil and Watershed Assessment Tool
TMDL	Total Maximum Daily Load
TOM	Task Order Manager
TP	Total Phosphorous
TSS	Total Suspended Solids
UWGB	University of Wisconsin – Green Bay
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
NRCS	USDA Natural Resource Conservation Service
WDNR	Wisconsin Department of Natural Resources

A3 Distribution List

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Attn: Paul Baumgart

Camp Dresser & McKee Inc.
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Chicago, IL 60606

Attn: Daniel Bounds

A4 Project/Task Organization

U.S. Environmental Protection Agency (EPA) Region 5 is funding this project, through a task order under EPA's Watersheds contract (no. 68-C-02-109) with The Cadmus Group, Inc. The Cadmus Team includes staff from the University of Wisconsin Green Bay (UWGB) and Camp Dresser & McKee Inc (CDM).

Kevin Pierard, the EPA Region 5 Watersheds and Wetlands Branch Chief, and Jo-Lynn Traub, the EPA Region 5 Water Division Director, will provide oversight for this contract. They will review and approve the QAPP and ensure that all contractual issues are addressed as work is performed on this task order.

Dean Maraldo will provide overall project/program oversight for this study as the EPA Region 5 Contracting Officer's Representative (COR). The EPA Region 5 COR will work with Chi Ho Sham, the Cadmus task order leader (TOL), to ensure that project objectives are attained. The EPA Region 5 COR will also be responsible for providing oversight for selection of BMP scenarios for model optimization; coordinating with contractors, reviewers, and others to ensure technical quality; and adhering to project and objectives and contract requirements.

The EPA Region 5 QA Officer, Simon Manoyan, will be responsible for reviewing and approving this QAPP. I n addition, he will conduct external performance and system audits and participate in Agency QA reviews of the study.

The Cadmus Team TOL is Chi Ho Sham. As Project Director, Dr. Sham will supervise activities conducted under the contract, as well as project oversight and review of all deliverables. Ms. Laura Blake will perform Project Manager duties, including coordination of conference calls with EPA, oversight of the selection of BMP scenarios for the cost optimization analysis, QAPP submission, and development of fact sheets and other outreach material. Dr. Julie Blue will serve as the QA Officer and will be responsible for oversight of QAPP development. Mr. Paul Baumgart (UWGB) will apply the Soil and Watershed Assessment Tool (SWAT) for the Green Bay AOC/Lower Fox River Watershed and provide model output (e.g., nutrient loading estimates) for use in the cost optimization analysis. Mr. Baumgart has extensive experience applying the SWAT model in the Green Bay AOC/LFR Watershed. Dr. Sam Ratick is the optimization modeler for the project. Dr. Ratick will conduct the optimization exercise to evaluate the implementation costs associated with the various best management practices (BMPs) and the associated benefits (i.e., pollutant load reductions). Mr. Daniel Bounds (CDM) will coordinate with other CDM offices and provide robust cost estimates relating to the various point and nonpoint control strategies and BMPs to be analyzed as part of the cost optimization.

A5 Project Description and Background

Introduction

U.S. waters continue to receive significant amounts of pollutant loading, much of which originates from nonpoint sources. Section 303(d) of the Clean Water Act (CWA) and EPA guidance require states to identify waters that fail to meet (or are not expected to meet) water quality standards. Such waters are considered water quality-limited and require the development of Total Maximum Daily Loads (TMDLs). Water quality models are useful planning tools for assessing these types of pollution problems.

Nonpoint source pollution (NPS) is considered a primary threat to the quality of waters in the country. Section 319 of the Clean Water Act presents guidelines for the implementation of state NPS management programs; specifically, the guidance documents urge state NPS programs to implement a watershed approach. This entails the development of watershed-based plans that should identify sources of pollutants, describe management measures necessary to achieve pollutant (nitrogen, phosphorus, sediment) load reductions, and estimate these resulting pollutant load reductions.

Background

Green Bay, a world-class freshwater resource, is impaired by excessive phosphorus and sediment loading from the Lower Fox River. The Wisconsin Department of Natural Resources (WDNR) 2004 303(d) list of impaired waters includes the Green Bay AOC and 13 impaired waters in the Lower Fox River (LFR) Watershed; these segments are listed for impairments resulting from sediments, low dissolved oxygen, and excessive nutrients. This project will attempt to develop the most cost-effective combination of implementation approaches for restoring the Green Bay AOC and LFR Watershed using an integrated watershed approach (IWA).

Objectives

This project will develop the most cost-effective combination of implementation approaches to address the phosphorus and sediment impairments in the Green Bay AOC and LFR Watershed. This will be accomplished through the use of existing data and the SWAT model developed by Arnold et al. (1996), and calibrated for the Green Bay AOC and LFR Watershed by Paul Baumgart. Scenarios will involve combinations of agricultural, urban, and construction site BMPs and variable adoption rates, as well as point source controls, which will target reductions of total phosphorus (TP) and suspended sediment (SS).

Specific objectives include:

- Estimating the costs for source controls to target TP and SS reduction.

- Developing ten alternative management scenarios, composed of multiple best management practices (BMPs) and policy initiatives.

- Utilizing the SWAT model to simulate the effects of the alternative management scenarios for the Green Bay AOC and LFR Watershed.

- Determining which alternative management scenario is lowest cost and results in attainment of water quality standards.

- Developing a transferable process for developing a cost-effective water quality management plan that includes a mix of BMPs and policy measures that will be acceptable to stakeholders, and result in attainment of water quality standards.

- Summarizing the pollutant reduction scenarios that resulted in the attainment of water quality standards.

- Describing in the final report how the integrated watershed approach can assist in the implementation of a cost-effective water quality management plan.

A6 Project/Task Description and Schedule

Task 1 – Project Planning and Support

Subtask 1.1 – Scoping Conference Call

On September 28, 2006, Cadmus convened a scoping conference call with the EPA Task Order Manager (TOM), EPA technical support staff, and others identified by EPA (e.g., WDNR staff). On October 3, 2006, Cadmus submitted a summary of the call to the EPA TOM and other call participants.

Subtask 1.2 – Project Kickoff Meeting/ Site Tour

The Cadmus Team participated in a two-day kick-off meeting and site tour on November 8 and 9, 2006, in Green Bay, Wisconsin. The technical leads from Cadmus and UWGB attended the kickoff meeting and provided a vehicle to accommodate 6 passengers for the site tour.

Subtask 1.3 – Monthly Progress Reports

Cadmus will prepare monthly progress reports and submit them (via a PDF attachment in an email) to the EPA TOM on the first of the month (for the previous month). Progress reports will be comprehensive, yet brief (1-2 pages) and include the following:

- Project objectives for the reporting period;
- Tasks and work conducted to meet objectives;
- Preliminary data and/or results;
- Technical issues or difficulties (and steps taken to avoid or resolve problems);
- Project objectives for next reporting period;
- Anticipated tasks and work for the next reporting period; and
- Project schedule status

Subtask 1.4. – Community Involvement Support

Cadmus will provide EPA with necessary assistance in preparing or presenting material that documents the status of the project and deliverables. Cadmus is prepared to develop any of the following public/stakeholder outreach materials: technical fact sheets; meeting agendas; briefing memoranda; presentation slides and/or handouts; and posters of maps, charts, or tables.

As needed, Cadmus will assist EPA in answering questions and presenting information concerning the project at up to two public meetings and/or workshops, as well as arrange for and operate audio-visual and other equipment at the meetings.

1.5 - Deliverables

All final deliverables, as defined in the TO SOW (e.g., reports) will be provided to the EPA TOM in both hard copy (4 copies of printed report) and electronic format (4 copies of CD). If needed, one hard copy and one electronic copy of the report will also be provided to WDNR.

1.6. - Project Closeout

At the completion of the project, all project files will be copied to a CD according to the format specified by EPA. Four copies of the data storage CDs will be submitted to the EPA TOM at the completion of the project.

Task 2 - Pollutant Reduction Optimization Exercise

Subtask 2.1 - Quality Assurance Project Plan (QAPP)

Cadmus is submitting to EPA this Secondary Data QAPP for the pollution reduction optimization exercise and modeling effort. The QAPP addresses all of the requirements from Attachment 1 of the Statement of Work ("QAPP Requirements") and describes, in detail, the steps to be followed to achieve the objectives of this project. In addition to outlining the project objectives and organizational structure, the QAPP identifies and summarizes the sources and quality of secondary data used for the pollution reduction optimization exercise and modeling effort. The QAPP summarizes the proposed model applicability to the project and highlights the strengths and weaknesses of the model. The QAPP outlines the procedures for validating and reporting final results. The QAPP includes a table and maps that show the project area, summarize available data, and identify stream segments and the impaired areas. The QAPP includes a map that shows U.S. Geological Survey (USGS) monitoring stations in the Lower Fox River Watershed. If needed, Cadmus will provide maps in larger, poster format. EPA and the state will provide comments on the draft QAPP within thirty calendar days after receipt. The final QAPP will be submitted within seven calendar days after receipt of comments.

Subtask 2.2 - Pollutant Reduction Optimization Analysis

The SWAT model will be applied by Mr. Paul Baumgart of UWGB to conduct scenarios that will simulate the effect of alternative land management practices and policy initiatives at the sub-watershed, watershed, and basin scales. The project area is shown in Figure 1. Impaired waters within the project area are shown in red in Figure 2. Incorporating the modeling results from the load reduction scenarios and the costs for implementing the various load reduction strategies in an optimization framework (e.g., using mathematical programming) will allow EPA, WDNR, and other stakeholders to gain a better understanding of the tradeoffs and cost-effectiveness of the various approaches to reduce pollutant loads (e.g., nutrients and sediment) that are the causes of impairments in the Lower Green Bay and the LFR Watershed. More importantly, results from the SWAT model and the optimization exercise will serve as the basis of the development of the TMDLs for the impaired waters.

Scenarios will be formulated and assessed by stakeholder/community groups assembled by the Lower Fox River Partners and others. Alternative implementation scenarios to be simulated will be based on those simulated by Baumgart (2005) and may include: (1) adoption of recommended nutrient management practices; (2) adopting P reduction techniques based on watershed or on-farm mass balance considerations (Erb, 2000); (3) reduced tillage practices; (4) installation of riparian buffer strips; (5) innovative manure management practices such as composting, digestion, or electrical generation; (6) urban stormwater and construction site controls; (7) point source controls: and most importantly (8) combinations of practices aimed at reducing TP and SS export to levels recommended by the Green Bay Remedial Action Plan (WDNR 1993, GBRAP 2000).

The SWAT Model will be used to identify, quantify, and evaluate TP and SS sources at the Lower Fox River Watershed Monitoring Program (LFRWMP) monitoring stations, sub-watershed, watershed, and basin scales. The available data will be incorporated in the SWAT model of the LFR basin. Mr. Baumgart (2005) successfully developed and applied a SWAT model for the allocation of TP and SS loads from the LFR basin and he concluded that: (1) the modified and calibrated SWAT model performed well during the calibration and validation periods that were examined; and (2) direct comparisons between individual events, statistical measures, and graphical relationships support the conclusion that the model can be applied to predict SS and TP loads at the sub-watershed and watershed scales with an acceptable degree of accuracy.

Mr. Paul Baumgart will refine and enhance the LFR basin SWAT model framework by re-calibrating and validating the model with continuous flow and daily loads of SS and P from five USGS stations operated through the LFRWMP (Figure 1). Data from 16 rain gauges funded through the LFRWMP will also serve as input to the model. It is likely that only the first two years of this data set will be certified by the USGS and available in time for use in Phase 1 of this project. We believe it is necessary to refine the previous modeling exercise because this previous effort relied heavily on daily loads from Bower Creek. If data become available and time permits, the stream bank erosion component of the model may be further calibrated with data obtained through a sediment transport study that has been proposed by UWGB.

Task 3. Reporting - Pollutant Reduction Optimization Findings

Subtask 3.1. - Draft Pollutant Reduction Optimization Summary Report

Cadmus will submit a draft of the Pollutant Reduction Optimization Summary Report to the EPA TOM by no later than May 31, 2007.

Subtask 3.2. - Final Pollutant Reduction Optimization Summary Report

The final Pollutant Reduction Optimization Summary Report will be submitted to the EPA TOM within 30 calendar days of receipt of EPA comments on the draft report. The Cadmus Team will also submit all applicable data files, model input files, and a working version of the model on CDs.

Project Schedule

The project schedule is provided as follows:

Submission	**Due Date**
Project Start	September 21, 2006
Monthly Progress Reports	1st of the Month
Scoping Conference Call	September 28, 2006
Project Kickoff Meeting/Site Tour	November 8-9, 2006
Quality Assurance Project Plan (QAPP) and Supporting Maps	December 15, 2006
Draft Pollutant Reduction Optimization Summary Report	May 31, 2007
Final Pollutant Reduction Optimization Summary Report	Within 30 calendar days of receiving EPA comments on Draft Pollutant Reduction Optimization Summary report
Project Closeout – electronic project files	September 21, 2007

A7 Data Quality Objectives and Criteria for Model Inputs/Application

Input Data Criteria

All input data acquired for the model must conform to QA/QC procedures established by the source agency (e.g., state). Under this project, model input data were collected by local agencies, prior to the specific scoping of the modeling project. It is assumed that all of the data acquired for the model calibration has been previously reviewed and verified for conformance to standard QA/QC requirements. The agencies providing the data are responsible for ensuring that data are properly reviewed and verified for integrity. All stream flow and water quality data were obtained from the USGS and has conformed to their QA/QC requirements. We do not anticipate utilizing provisional 2006 USGS water year data from the USGS, but will duly note so if we believe that including the data is helpful.

The Cadmus Team will conduct an initial overview of the data to assess the suitability of the data for use in model development. The Cadmus Team has conducted an initial overview of the stream flow and water quality data from the USGS and has determined that most of the data are suitable for use in model development. However, some of the stream flow and loads estimated by the USGS during ice-affected periods, which affect stage-discharge relationships, may not be suitable for calibration or validation of the model. Ice-affected periods that significantly affect discharge and loads will be reported. Cadmus will identify and document other data quality issues if they arise. Evaluation of model results will take any uncertainties related to model input data, as well as the quality of the final measured data set and budget constraints, into consideration. If necessary, the data will be converted by the project team to the units and projection needed to run the model, as a single projection must be utilized for all data sets in order to run the model.

Geographical Information System and Land Use Representation: A Geographical Information System (GIS) based on ArcGIS software will be used to generate model inputs that will be exported into SWAT model formatted files. The SWAT model will be efficiently integrated with the GIS using spreadsheet and database software through the use of scripts or macros that offer operational speed and flexibility. Through this efficient interface, it will be feasible for the Cadmus Team to simulate a large number of complex nutrient and crop management practices at the sub-watershed level. This is important for this current project because crop rotations and manure management in the study watersheds and sub-watersheds can be complex and difficult to simulate through limited management options (Baumgart 2005).

The GIS data layers utilized by Baumgart (2005) may be supplemented if more recent data are available and there is sufficient time and resources within the project time period to incorporate these data into the model framework. At a minimum, the GIS sub-watershed boundary layer created by Mr. Paul Baumgart will be revised to coincide more closely with the water quality monitoring stations established by the LFRWMP. The land use Geographic Information System (GIS) layers, also created by Mr. Paul Baumgart, which reflect baseline year 2000 and future conditions may be supplemented as needs and resources permit (e.g., land use during LFRWMP monitoring period).

Urban Stormwater: The urban storm water and construction site TP and SS yields and potential reductions simulated by Baumgart (2005) will be compared to results from other models or published data and refined or supplemented as needed. CDM will collect cost and pollutant removal efficiency of various urban stormwater BMPs.

Point Source Controls: The existing database of point source TP and SS loads will be updated with data obtained from the WDNR. CDM will collect cost and pollutant removal efficiency data for various point source control strategies. CDM has worked extensively with many wastewater treatment facilities and developed an extensive knowledge base for the cost for point source controls.

Nonpoint Source Controls: The land use GIS layers which reflect baseline year 2000 and future conditions, as discussed above, will provide a baseline for estimating pollutant loads and the deployment of control strategies. The Cadmus Team will incorporate additional research findings (e.g., from the Wisconsin Buffer Initiative) and other research on wetland function and current scientific literature on the costs and efficiency of pollutant removal by the various BMPs and control strategies.

Data Quality Objectives for Model Application

All model applications typically include three primary phases or steps: database development, system characterization, and calibration and validation. QA issues are involved in all aspects of model application, but they are especially critical for the calibration and validation phase because the outcome establishes how well the model represents the watershed. An accurate numerical representation of the study area is the primary goal of the model application effort because it determines whether the model results can be relied upon and used effectively for decision- making.

The USEPA Modeling QAPP Guidance (USEPA, 2002) specifically emphasizes model performance criteria, which are the basis by which judgments will be made on whether the model results are adequate to support the decisions required to address the study objectives. Therefore, the quality assurance process related to SWAT calibration includes documentation of the expected accomplishments of the calibration and consideration and discussion of how implementing the calibration procedures improve the predictive quality of the model.

The specific limits, standards, goodness-of-fit, or other criteria (e.g. the percentage difference between reference data values from the field or laboratory and predicted results from the model) on which a model will be judged as being properly calibrated will be assessed. Initially, time series plots are generally evaluated visually as to the agreement, or lack thereof, between the simulated and observed values. Subsequent statistical tests, discussed below, are used to further quantify the calibration fit. Scatter plots usually include calculation of a correlation coefficient, along with the slope and intercept of the linear regression line; thus the graphical and statistical assessments are combined. When observed data are adequate or uncertainty estimates are available, confidence intervals for the observed data will be calculated so they can be considered in the model performance evaluation. There are a variety of ways to compare simulated and observed mean values. For example, the sporadic observed data can be aggregated over annual, seasonal, or monthly timeframes and compared to the full range of simulated values.

Calibration and validation of the SWAT model will involve comparing the simulated stream flow and loads to the USGS observed values and computing the square of the Pearson correlation coefficient (r-squared) and the Nash-Sutcliffe coefficient of efficiency (NSCE; Nash and Sutcliffe 1970). R-squared and NSCE values of 0.6 or greater will serve as criteria to indicate successful calibration and validation of the model for stream flow, TSS loads and TP loads on an annual, monthly, and potentially event or daily basis. While we expect to achieve r-squared and NSCE values that are greater than 0.7 at most of the monitored streams, we recognize that it may not be possible to obtain values greater than 0.45 at one or two streams for some parameters. If the latter situation occurs, the model may still be deemed valid for the LFR watershed as long as such excursions from our targets are limited in scope.

To compare baseline conditions and alternative management scenarios, the SWAT model will be applied over a 1977 to 2000 long-term climatic period and TP and SS loads will be summarized on an average annual basis to ensure that typical climatic conditions are represented. Load contributions from different agriculture land practices, other rural sources, urban areas, land development sources, and point sources will be summarized by sub-watershed, watershed, and basin. SWAT model output data will serve as input to the optimization model. The costs and load reductions from the approximately 10 pollution reduction scenarios will be used in an optimization model or optimization models (e.g., linear programming, mixed integer programming, or dynamic programming) to assess the cost-effectiveness of the various pollution reduction strategies that can be deployed across the watershed. Jim Baumann, WDNR TMDL expert reviewed the technical merits of Baumgart's (2005) application of the SWAT model, and found it to be satisfactory.

Confidence in model predictions of current and projected TP and SS load estimates will be limited by a number of factors including: similarity of modeled watersheds to characteristics of the calibration areas; watersheds that have no monitoring data, yet have loadings that do not reflect expected relationships with monitored watersheds; knowledge of actual nutrient and tillage management practices (e.g., timing, rate, location, and depth of manure application); inherent ability of the model or model framework to predict the outcome of various nutrient and tillage management practices; lack of measured P and SS loads from urban or urbanizing sources within the LFR basin; and knowledge of future conditions when making predictions. In addition, certain valuable data (e.g., data on buffer strip effectiveness) may be at a different spatial resolution (e.g., higher spatial resolution at sub-acre level). The Cadmus Team will clearly note the limitations associated with the model and data in the final report.

A8 Documentation and Records

All documentation, including the QAPP, progress reports, records of monthly meetings, and final reports will be developed by Cadmus, UWGB, and CDM and, when appropriate, will be presented through spreadsheet summaries, graphical analysis, and GIS maps. At the completion of the project, a set of compact discs (CDs) containing the final project files used for the model, including the model, specific model data inputs, GIS layers, simulation, and calibration files will be included with the final report.

Section B – Measurement and Data Acquisition

B1 SWAT Calibration/Sensitivity Analysis

SWAT Model

SWAT was developed by the USDA-ARS to improve the technology used in the SWRRB model (Simulator for Water Resources in Rural Basins; Williams et al., 1985; Arnold et al., 1990). SWAT is a distributed parameter, daily time step model that was developed primarily to assess non-point source pollution from watersheds and large complex river basins. SWAT simulates hydrologic and related processes to predict the effect 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. In addition, point source loads and outputs from other models can be input to the model. Major crop and management components used in the EPIC model (Sharpley and Williams, 1990) have been added to SWAT; consequently, it can better represent the actual cropping, tillage and nutrient management practices typically used in Northeastern Wisconsin. Modeled output data from SWAT can be input easily to a spreadsheet or database program, thereby facilitating efficient modeling of large complex watersheds with various management scenarios.

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 submodel to simulate nutrient transport.

SWAT allows the use of a separate input file for each subwatershed, hydrologic response unit, routing reach, soil, groundwater, pond/wetland, management practice, stream water quality reach, and chemical type. A number of other files are also utilized by SWAT including: basin, weather, tillage, crop, pesticide, fertilizer, irrigation, reservoir, lake water quality, and routing configuration files. Control of these files is managed through a single "control-inputoutput" file which allows for much flexibility. At the current scale of operation, the SWAT model, along with other supplemental data (e.g., data from Wisconsin Buffer Initiative – at a more refined spatial resolution) may be the best way to address the pollutant reduction approaches.

Model Calibration & Validation

Model calibration involves adjusting model inputs within acceptable ranges to obtain a good fit between observed and simulated values. The model will be calibrated for crop yields and biomass, after which it will be calibrated for stream flow. After the model is successfully calibrated for flow, the model will be calibrated for suspended sediment and phosphorus. The Upper Bower Creek watershed (LF01-15, 36 km^2) previously used by Baumgart (2005) as a calibration site will again serve as the primary calibration site for stream flow, suspended sediment loads, and phosphorus loads in the model refinement phase. This monitoring site (USGS Station #04085119) is located in the East River Watershed (and was jointly funded by the USGS and WDNR) has a continuous record of flow data, which is vital to the model calibration. The Upper Bower Creek watershed has silty clay to clay loam soils with slow infiltration rates (NRCS hydrologic group C soils), shallow overland slopes, and landuse that was 83% agriculture (mostly dairy) and 9% forest and wetland in 2000. These characteristics are typical of most areas within the LFR watershed, where landuse in 2000 primarily consisted of agriculture (53%), urban (29%), and forest and wetlands (14%). A 1990 to 1994 data set will be used for calibrating the model (50 events), while the data set from 1996-97 (17 events), along with data from other sites, will be used in the model assessment phase. Subsets of stream flow and constituent loads from the USGS stations listed in Section B2 will serve to supplement the initial model calibration, and to validate the model.

Model Validation

Model validation will involve testing the ability of the calibrated model to predict flow and loads at times or locations other than those in the calibration phase, without adjusting model parameters. The Nash-Sutcliffe coefficient of efficiency (Nash and Sutcliffe 1970), regression analysis, and visual inspection will be the criteria used to compare observed and simulated flow and loads on an event, monthly, and annual basis. The SWAT model will be applied for periods which coincide with stream flow and water quality measurements (calibration/validation model runs) and for a 1977 to 2000 long-term climatic period using daily precipitation and temperature data. Daily flow, TSS, TP, and dissolved TP loads will be simulated. The typical sub-watershed area to be modeled will range from 20 to 80 km^2. Existing SWAT model inputs and other data sets developed by Baumgart (2005) will be supplemented where needed. The more robust model will then be applied to compute the outcome of more complex management scenarios than those previously simulated by Mr. Baumgart.

Sensitivity Analysis

Following model calibration, a sensitivity analysis will be conducted to assess the influence of selected key inputs on simulated suspended sediment, phosphorus and stream flow. To perform this analysis, the Natural Resource Conservation Service (NRCS) curve number (CN), manure depth fraction, soil available water capacity (AWC), soil labile phosphorus concentrations or other inputs will be adjusted in the primary calibration subwatershed LF01-15 to determine the sensitivity of the SWAT model to changes in each of these parameters.

B2 Non-Direct Measurements (Data Acquisition Requirements)

SWAT

To provide for a high-quality input database, model input data were acquired from a variety of qualified sources, including federal, state, and tribal agencies and universities (Table 1). Input data include:

Geographical Information System Data Layers - The following GIS layers and images will be utilized to construct GIS layers needed to provide inputs to the SWAT model. Most of these inputs have already been assembled by Baumgart (2005), but they may be modified with more recent data.

- 1:24k WDNR watershed boundaries
- East River subwatershed boundary coverage from the Bay Lakes Regional Planning Commission
- Upper East River subwatershed boundary coverage from the USGS
- USEPA 12-digit HUC LFR watershed boundary
- Digital soil surveys from Brown, Calumet, Outagamie and Winnebago counties (SSURGO)
- WDNR 30 meter digital elevation model (DEM), used to derive overland slope
- 1:24k surface water hydrology from WDNR
- USGS 1:24k Quadrangle Digital Raster Graphic Images - topographic maps
- WISCLAND 1992 Land Cover, based on satellite imagery, from WDNR
- Land use images and maps from the East Central Wisconsin Regional Planning Commission
- Land use GIS shapefiles from the Brown County Planning Department
- Miscellaneous: roads, county boundaries, etc. from the WDNR
- Brown County buffer strip coverages and associated stream hydrology layer
- 1992, 2000, 2005 Digital orthophotos for Brown, Calumet, Outagamie and Winnebago counties, provided by the counties, WDNR, or USDA-FSA

Stream flow and water quality data - Calibration and validation of the SWAT model will be conducted with stream discharge and water quality data from the following USGS monitoring stations:

1) Bower Creek at CTH MM (1990-1997; 36 km^2)
2) Duck Creek at CTH FF (1988-2002; 276 km^2)
3) East River at Midway (1993-95; 122 km^2)
4) East River at Monroe Street (1985-86; 374 km^2)

Daily stream flow from the USGS is available for all the above sites. Daily TP and TSS loads were calculated by the USGS for Bower Creek and the East River at Monroe St. sites.

In addition, five continuous discharge monitoring stations within the 1,580 km^2 Lower Fox Basin were upgraded or installed through the LFRWMP and were operated cooperatively with the USGS, the Oneida Tribe, and the GBMSD. Three years of discharge and water quality data (phosphorus and TSS) from October 2003 through September 30, 2006 are available for the following stations:

1) Duck Creek at CTH FF (276 km^2), upgraded with sampler (co-sponsored by Oneida Tribe)
2) Baird Creek at Superior Road (54 km^2)
3) Apple Creek at CTH U / Campground (117 km^2)
4) Ashwaubenon Creek at Creamery Road (48 km^2)
5) East River at Monroe Street (374 km^2), (co-sponsored by the GBMSD)

The USGS computed daily TP and TSS loads for each stream based on continuous discharge and discrete low-flow and automated event sampling. The UW-Green Bay will use regression analysis to estimate dissolved phosphorus loads. Data from USGS water year 2006 is currently provisional, so it will not be included in data analysis without disclosing this fact.

Climatological Inputs - Daily precipitation and temperature data from the following weather stations will serve as input to the climate sub-model in SWAT: NOAA National Weather Service (NWS) Station at the Green Bay airport (long-term); three USGS stations located in the Upper Bower Creek watershed (1990-97); a station near Greenleaf operated by the University of Wisconsin (1993-96); and official NWS cooperative stations in Appleton and Brillion (long-term). In addition, four rain gauge-logger units were operated by the USGS (2003-06), and 12 tipping bucket rain gauges and loggers have been installed throughout the basin by UWGB through the LFRWMP (2004-2006).

Agricultural Practices - Model inputs from Baumgart (2005) will be revised where necessary. Tillage practice and crop residue inputs to SWAT will be obtained from Transect Survey data compiled by the NRCS and county Land Conservation Departments. Crop inputs will be derived from county-wide agricultural statistics published in the annual Wisconsin Agricultural Statistics series. Local agricultural experts from the NRCS, county Land Conservation Departments, consultants, University of Wisconsin Extension, and other sources will provide expert advice on agricultural practices and scenario development.

Table 1. Data Input Types and Sources

Data Coverage	Source Agency	Source Location/Metadata Link
Elevation (DEM)	WI Dept. of Natural Resources	ftp://gomapout.dnr.state.wi.us/geodata/elevation/ Metadata for most WDNR layers available at ftp://gomapout.dnr.state.wi.us/geodata/metadata/ and/or included at data site in ZIP file
Elevation and contours	Brown County Planning Dept.	Data utilized only as needed in this phase. http://www.co.brown.wi.us/Land_Information_Office/IMS.htm
Elevation and contours	Outagamie County Planning Dept	Data utilized only as needed in this phase. http://www.co.outagamie.wi.us/applications/arcims/public/html/

Data Coverage	Source Agency	Source Location/Metadata Link
WDNR-Enhanced USGS 1:24K DRG topographic maps	WI Dept. of Natural Resources	http://dnrmaps.wisconsin.gov/webview/themes/drg.html http://dnr.wi.gov/maps/gis/documents/digital_raster_graphics_24k.pdf
Hydrography	WI Department of Natural Resources - surface water	Utilized earlier version (available on request): most recent version at ftp://gomapout.dnr.state.wi.us/geodata/hydro_24k/
	WI Department of Natural Resources - watershed boundaries	Utilized earlier version (available on request): most recent version at ftp://gomapout.dnr.state.wi.us/geodata/watersheds/
	Bay-Lake Regional Planning Commission - watershed boundaries	Lower portion of East River only. Available on request from source. GIS web site: http://www.baylakerpc.org/
	USGS - Wisconsin, watershed boundaries	Upper portion of East River only. Data available on request from source.
	USEPA - watershed boundaries	Draft 12-digit HUC obtained from EPA, available on request. Utilized for comparison purposes.
	LFRWMP - Final watershed boundaries	Available on request. Compiled and modified from above layers http://www.uwgb.edu/watershed/data/index.htm
Hydrography - 303(d) Impaired surface waters	WI Department of Natural Resources	Available on request from source. Contact: Matt.Rehwald@dnr.state.wi.us
Landuse/Landcover and ortho-photos	WI Department of Water Resources	WISCLAND landcover: ftp://gomapout.dnr.state.wi.us/landcover/ ftp://gomapout.dnr.state.wi.us/metadata/
	Brown County Planning Dept.	Available on request to data source. GIS web site: http://www.co.brown.wi.us/Land_Information_Office/IMS.htm
	Outagamie County Planning Dept.	Available on request to data source. GIS web site: http://www.co.outagamie.wi.us/applications/arcims/public/html/
	East Central Wisconsin Regional Planning Commission	Available on request to data source. GIS web site: http://www.eastcentralrpc.org/
	USDA - FSA, from Wisconsin View	NAIP color ortho-photos http://www.wisconsinview.org/ http://www.wisconsinview.org/documents/2005_NAIP_FAQs.pdf
Soil Types (SSURGO)	US Dept. of Agriculture - NRCS	Wisconsin: Brown, Calumet, Outagamie, Winnebago Counties http://soildatamart.nrcs.usda.gov http://soildatamart.nrcs.usda.gov/SSURGOMetadata.aspx
Meteorological: Daily rainfall,	NOAA Daily Climatic Data from NWS and coop	Data available on request. Data obtained from UW-Extension Geological and Natural History Survey

Data Coverage	Source Agency	Source Location/Metadata Link
temperature and monthly statistics	stations	State Climatology Office in Madison, Wisconsin
	USGS: 4 tipping buckets/loggers at USGS gages, plus Bower Creek stations	Rainfall data on request from source. See also: http://www.uwgb.edu/watershed/data/climate.htm
	LFRWMP: 12 tipping bucket gauges with loggers	Rainfall data on request. http://www.uwgb.edu/watershed/data/climate.htm
Stream Flow & Water Quality (TSS and TP loads)	USGS	http://waterdata.usgs.gov/wi/nwis/sw Bower-04085119; Baird-040851325; East-040851378; Fox-040851385; Ashwaubenone-04085068; East-Midway- 04085109; Apple-04085046; Duck-04072150
	LFRWMP	Discharge and load data on request - http://www.uwgb.edu/watershed/data/index.htm
Roads	Brown County Planning; Outagamie County Planning; WI Department of Natural Resources	Data available on request from source. More recent data from U.S. Census Bureau to be gathered if needed to supplement existing GIS road networks: http://www2.census.gov/geo/tiger/tiger2006fe/WI/ http://www.census.gov/geo/www/tiger/tiger2006fe/tl2006femeta.txt
Political Boundaries	WI Department of Natural Resources	ftp://gomapout.dnr.state.wi.us/geodata/county_bnds/
Vegetated Buffer Strips	Brown County Land Conservation Department	GIS layer available on request from source.
Point Source Loads	WI Dept. of Natural Resources	

BMP Cost Estimates

The major objective of the pollutant reduction optimization exercise is to develop the most cost-effective combination of implementation approaches to address the nutrient impairments in Lower Green Bay and the Lower Fox Basin. Estimates of probable costs will be developed for various alternative management scenarios, composed of multiple BMPs and policy initiatives, and the alternative management scenarios will be evaluated based on cost efficiency. Estimates of probable costs will include both capital (construction) and long-term implementation (operation and maintenance, O&M) costs. Reliable planning-level estimates of probable cost will be based on regionally recognized reference materials that provide cost ranges, such as the *Evaluation of Stormwater Reduction Practices* (Center for Watershed Protection, 2003), and estimates made by licensed and experienced civil engineers with access to accepted regional costs.

Licensed and experienced engineers will use available regional cost data to develop estimates of probable unit costs for each BMP, and scale the costs up according to the BMP scenario results produced from project analysis. For each BMP, costs for the following components may be considered: earthwork and excavation, land acquisition, necessary equipment and mechanical infrastructure, planting and landscaping, and reservoir/storage.

The capital cost of each BMP will be built up from:

- Construction labor, equipment, and materials
- Mobilization and demobilization (at 3% of construction)
- Contingency (at 30% of construction)
- Land acquisition
- Engineering, survey, legal, and permitting (at 20% of construction)

The implementation (O&M) cost will be based on a 20-year BMP life cycle, and will be built up from:

- O&M labor
- Electrical power (if necessary)
- Chemicals(if necessary)
- Maintenance equipment and supplies

B3 Data Management

The GIS files, stream discharge, water quality, and other model input datasets collected for this modeling project are in ESRI shapefile, Microsoft Excel spreadsheet, and LOTUS 1-2-3 spreadsheet formats and currently stored on a restorable project hard drive while the project work is being performed. At the completion of the modeling project, a set of compact discs or a DVD containing the final project files used for the final model, including the model, specific model data inputs, GIS layers, simulation, and calibration files will be included with the final modeling report.

Section C – Assessment and Oversight

C1 Assessment and Response Actions

The Project Officer and the Cadmus Project Team will meet on an agreed upon schedule to discuss progress of the project. All correspondence regarding the gathering of input data and model development shall be copied to the Project Officers. All model adjustments will be documented and reviewed by the project team.

C2 Reports to Management

Deliverables to be submitted for quality assurance purposes includes:

- Draft and final QAPP and supporting maps
- Monthly progress reports.
- Draft and Final Pollutant Reduction Optimization Summary Report
- Electronic project files

Section D – Data Validation and Usability

It is assumed that all of the data acquired for the model calibration has been previously reviewed and verified for conformance to standard QA/QC requirements. The agencies providing the data are responsible for ensuring that data are properly reviewed and verified for integrity. The Cadmus Team will conduct an initial overview of the data to assess the suitability of the data for use in model development. It is assumed that the agencies responsible for field data collection have thoroughly reviewed the data for accuracy, representativeness, sufficiency, and analytical quality prior to inclusion in the database transmittals to the Cadmus Team. These standard QA/QC procedures should include checking all data for errors, especially errors in transcription, calculations, and data input. Cadmus will identify and document data quality issues if they arise.

Model validation will be conducted as described above under section B1 – SWAT Calibration/Sensitivity Analysis. The greatest potential for error with stream flow and associated loads is during periods affected by ice conditions in the stream, which can greatly affect stage-discharge relations. Calibration and validation comparisons between measured and simulated data during these periods will be documented.

The greatest uncertainty with model inputs is likely to occur with on-the-ground management of agricultural practices. That is, how, when, and where a farmer actually applies a particular practice such as applying manure can vary widely, as can the associated impacts on water quality. Much of this type of information is undocumented. For example, many farmers in the LFR watershed plow furrows throughout a field after fall harvest to improve drainage. Despite the likely adverse effects on water quality, this practice doesn't appear to be well-documented. Some of these fields may even have cover crops or conservation tillage intended to reduce erosion. Chisel plowing a field parallel to the stream protects water quality more than plowing in the same direction as the crop rows. In addition, some farms have well-documented details of farm management, while many others do not at this time. Where detailed documentation of management practices at the farm level exist, they have not yet been compiled at a watershed or county-wide scale in a manner suitable for input to a watershed-scale model in the project area.

Models, by their nature, are simplifications of natural systems, so averaging of inputs over space and time is necessary. The nature of this averaging may affect the accuracy of the model and, potentially, the applicability of model predictions under certain circumstances.

Accuracy of BMP Cost Data

Construction costs vary over time, including variability in material costs and construction and long-term maintenance labor rates. Licensed and experienced engineers will use local costs and rates and engineering judgment to produce accuracy in costs. The anticipated accuracy of the BMP scenario estimates of probable costs could range from approximately 10% below the BMP scenario’s estimate, to approximately 30% above the estimate.

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APPENDIX B

SWAT MODEL REFINEMENTS

Model Inputs and Methods

The same model inputs and procedures utilized by Baumgart in 2005 and described in this project's Quality Assurance Project Plan (QAPP) (Appendix A) were utilized in this project with a few exceptions, as noted below.

Stream Water Quality Data

Stream flow and loads from the five LFRWMP USGS monitoring stations described in Section 2.5 were utilized for this project's model assessment. As stated in the QAPP, there were times when the stage-discharge relationship in a stream was affected by ice conditions, thereby affecting stream flow and calculation of associated loads. During these times, USGS estimated flow. However, there were times when it appeared that the estimated stream flow was too high relative to the overall water balance and expected water inputs. That is, the water balance during and preceding the ice-affected flow events did not seem correct in the sense that the flow volume came close to, or even exceeded total precipitation during or preceding the event. Stream flow and associated loads estimated by USGS during ice-affected periods were therefore adjusted by Paul Baumgart. Total phosphorus and suspended sediment loads were adjusted in proportion to the change in flow. Flow and loads in 2004 and 2005 were modified at the LFRWMP monitoring sites as follows: Apple Creek (3 events); Ashwaubenon Creek (2 events); Baird Creek (none); Duck Creek (3 events); and East River (none).

In order to avoid potential bias, these ice-affected estimated flow and loads were adjusted before the model was run to estimate loads in the watershed. Although the adjustments often favored an improved correspondence between simulated and observed flows, there were also times when they decreased the fit.

Watershed Delineations

Subwatershed boundaries were altered slightly to coincide with the location of the LFRWMP monitoring stations so that simulated flows and loads could be directly compared to the measured values. Channel lengths, widths and slopes were altered for subwatersheds with the modified boundaries.

Climatological Inputs

As noted in the QAPP (Appendix A), 12 tipping bucket rain gauges and loggers were installed throughout the subbasin by the UWGB through the LFRWMP to supplement USGS and National Weather Service daily precipitation data. Unfortunately, most of the LFRWMP tipping bucket rain gauges were not installed until after June, 2004. Consequently, cumulative rainfall estimates from the NWS radar in Green Bay were utilized to estimate daily rainfall at missing stations and supplement directly measured data from available stations during five major rainfall events. Rainfall totals from existing stations served as ground truth during these five periods. Daily precipitation data from four independent stations that were part of a weather network whose real-time data was posted on the internet were also added to the climate database. This data set was checked for accuracy by comparison with nearby stations, and questionable data were removed from the database. During the calibration/validation period, precipitation inputs to the model were generated for each sub-watershed based on an inverse-distance weighted formula and the distance between the centroid of each sub-watershed and the surrounding precipitation stations.

Routing Channel Slopes

The channel slope input format was changed to increase the number of decimal points from 3 to 5 because the minimum slope with the former was 0.001 which is substantially higher than the shallow sloped lower portions of some of the major streams.

Tillage Practices and Crop Residue

The conservation tillage levels utilized by Baumgart (2005) were updated to coincide more closely with the recently acquired LFRWMP water monitoring data from 2003 to 2005. Conservation Technology Information Center (CTIC) Conservation Tillage Reports from the four counties were analyzed to determine the primary tillage practice inputs to SWAT. These "Transect Survey" reports were based on statistical sampling procedures of farm fields to estimate residue levels present shortly after spring planting, as well as other information. Data were supplied by the Wisconsin Department of Agriculture, Trade and Consumer Protection and analyzed with the Transect 2.16 software program produced by Purdue Research Foundation, Purdue University.

The most recent crop residue and tillage practice report (from 2002) indicated that there was a sharp decrease in the amount of residue left on the field since data had been collected in 1999 and 2000, especially for watersheds that had higher residue cover in the previous years. There was much variation in residue cover between watersheds, and some uncertainty in the applicability of the residue data because the water monitoring data was from late 2003 to late 2005 instead of 2002. Because of this uncertainty, the watershed-specific crop residue levels from 1999, 2000 and 2002 were averaged and applied uniformly as conservation tillage inputs to all of the watersheds in the LFR subbasin. The average tillage inputs that were assumed for the Baseline Conditions were: 83.1% conventional tillage, 15.2% mulch-till, and 1.7% no-till, zone-till or high residue for the dairy crop rotation; and 75.9% conventional tillage, 20.2% mulch-till, and 3.9% no-till for the cash crop rotation. One factor that may be decreasing residue levels is that farmers who are using a chisel plow are often utilizing a more twisted shank; thereby, causing a great deal of mixing and resulting in soil surface residue levels that are not that much better than if they had used a moldboard plow which completely turns the soil over. Although there has been a substantial increase in the proportion of farmers that are using a chisel plow instead of a moldboard plow, aggressive mixing of the soil with the chisel plow may be greatly reducing its potential for reducing soil erosion.

Stream Bank Erosion

Although many of the watershed plans in the LFR Watershed did not indicate that stream bank erosion was a large source of suspended sediment, it was also not insignificant. More importantly, urbanization appears to be altering the hydrology in some of the streams, thereby creating unstable stream banks and beds, particularly in the Baird Creek watershed (Fink 2005). Therefore, the stream bank component of the SWAT model was investigated to see how well it might simulate erosion from stream banks. While the model showed some promise, the effort was abandoned for several reasons: 1) there is no interaction in the model between predicted sediment losses from stream bank erosion and TP; 2) attempts to modify the model to make this connection were not entirely successful; 3) lack of robust stream bank data to calibrate the model; and 4) time constraints. If fully funded, a preliminary sediment source investigation now underway in LFR streams will greatly help to refine the stream bank component of the LFR SWAT model.

Model Assessment and Validation

Model assessment and refinement was 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 TP and SS from the five LFRWMP monitoring stations made it possible to further test the ability of the model to simulate flow and TP and SS loads with a reasonable level of accuracy.

Model validation, or assessment, involved testing the ability of the calibrated model to predict flow and loads at different times or locations than those used in the calibration phase. Model assessment and potential refinement were necessary because the previous LFR modeling effort relied heavily on daily loads from a single intensively-monitored USGS station (Baumgart 2005). With data made available through the LFRWMP, it was possible to thoroughly assess the ability of the model to provide reasonably accurate predictions in five LFR watersheds. Model assessment involved comparing the simulated output to continuous flow and daily loads of SS and TP from the five USGS stations operated and funded cooperatively through the LFRWMP, the Oneida Nation and the GBMSD. Only data from USGS water years 2004 and 2005 were utilized in this evaluation because data from 2006 were not certified by the USGS in time to be used in this project. The SWAT model was applied for a 2002 to 2005 climatic period for the model assessment phase.

Assessment Results

In general, the un-adjusted LFR subbasin model was able to estimate flow, SS loads and TP loads at the monitored sites with a reasonable degree of accuracy on a monthly and annual basis during the 2004 and 2005 USGS water year monitoring period. As summarized in Table 3-1, r-squared between observed and simulated monthly flow ranged from 0.84 to 0.94. The Nash-Sutcliffe coefficient of efficiency (NSCE; Nash and Sutcliffe 1970) ranged from 0.83 to 0.93. An NSCE of one indicates a perfect fit. There was a good correspondence between simulated and observed monthly flows during the validation period.

R-squared between observed and simulated monthly TP and SS loads ranged from 0.66 to 0.87, which are above the minimum criteria of 0.60 stated in the QAPP. The NSCE statistic for monthly TP loads ranged from 0.66 to 0.86. However, the NSCE statistic for monthly SS loads ranged from 0.59 at the East River to 0.77 at Apple Creek. Therefore, the un-adjusted model was not able to meet the minimum QAPP criteria of 0.59 at the East River site. Perhaps more importantly, the relative difference between the simulated and observed total SS loads at the East River stations was 45.6%, which is the primary reason for the monthly NSCE not meeting the criteria. As shown in Table 3-2, observed and simulated flows in 2005 were roughly one half to one third of the amount in 2004. TP loads followed a similar trend, whereas, the difference was much greater with SS loads which are greatly affected by events. The data summarized in Table 3-1 and Table 3-2 indicates that there was generally an acceptable level of correspondence between simulated and observed flow, and loads of TP and SS on a monthly and annual basis. However, the simulated SS load at the East River site in 2005 is much greater than the observed load.

The reason for the discrepancy at the East River site is not clear; however, it may be due to the difficulty in simulating the load at the mouth of the East River, which is essentially part of the lowest portion of the Fox River, which is greatly affected by water levels in Lower Green Bay, including the seiche induced flow reversals. Major flow reversals are common at the river outlet. The model may not be adequately simulating the effects of riparian wetlands, the Niagara escarpment, or other aspects of this watershed on SS, particularly during a relatively dry year such as 2005. There may also be difficulties in obtaining representative samples at this station with just the single sampler inlet. There have only been a limited number of simultaneous pump samples and Equal-Width-Increment (EWI) samples collected at this monitoring station during major runoff events, which may not be enough to ensure that the pump samples are truly representative, or can be accurately adjusted with a correction factor.

Table B-1. Simulated and Observed Monthly Flow, Suspended Sediment, and Total Phosphorus Statistics for WY 2004-05. Simulated results based on un-adjusted LFR calibration parameters. Relative differences are for the entire period.

Stream	Flow			Suspended Sediment			Total Phosphorus		
	R^2	NSCE	% Diff.	R^2	NSCE	% Diff.	R^2	NSCE	% Diff.
Apple	0.86	0.86	6.3%	0.87	0.77	-21.7%	0.81	0.81	-3.6%
Ashwaubenon	0.90	0.85	26.1%	0.69	0.69	1.9%	0.82	0.82	-3.1%
Baird	0.84	0.83	16.6%	0.66	0.65	-3.7%	0.70	0.66	-0.9%
Duck	0.86	0.84	-12.5%	0.77	0.75	3.0%	0.67	0.64	25.5%
East River	0.94	0.93	-8.0%	0.72	0.59	45.6%	0.86	0.86	7.6%

Table B-2. Annual Simulated and Observed Stream Flow, Suspended Sediment, and Total Phosphorus Yields in 2004 and 2005. Simulated results based on un-adjusted LFR calibration parameters.

Stream	Flow (mm)				Suspended Sediment (t/ha)				Phosphorus (kg/ha)			
	2004		2005		2004		2005		2004		2005	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Apple	322	346	141	146	0.93	0.66	0.12	0.16	1.89	1.81	0.57	0.57
Ashwaubenon	272	345	108	133	0.69	0.70	0.20	0.21	1.99	1.97	0.78	0.71
Baird	364	403	107	146	0.73	0.67	0.10	0.13	2.34	2.15	0.50	0.67
Duck	344	325	140	99	0.36	0.37	0.11	0.11	1.29	1.76	0.57	0.58
East River	339	322	173	150	0.49	0.63	0.06	0.19	1.63	1.61	0.46	0.64

The QAPP (Appendix A) noted that it may not be possible to obtain r-squared or NSCE statistics greater than 0.45 at one or two streams for some parameters, but the model may still be deemed valid as long as such excursions from our targets are limited in scope. The aforementioned excursion occurred only for SS at the East River, for which flow reversals can make it difficult to measure, as well as simulate, constituent loads. The model is therefore judged to be valid, and can be applied to reliably predict flow and loads of SS and phosphorus from the LFR watersheds. However, some adjustments were made to the model because of the tendency for the model to overstate SS loads from the East River and to a lesser degree, TP loads from Duck Creek.

Model Adjustments

No adjustments were required for any of the watersheds except for the East River, where the stream power concentration parameter (SPCON) was decreased from 0.0008 (800 mg/L) to 0.0005 (500 mg/L), which reduced the SS load but did not affect phosphorus because the latter is only affected by the QUAL2e water quality sub-model, and not the sediment transport sub-model. Lowering the SPCON effectively decreases the amount of sediment that can be re-entrained for a given flow, and transported downstream. The data set was not separated into calibration and validation data sets and evaluated again because the model had already been shown to be valid for the LFR watersheds. Additional monitored data now being gathered may be used at a later date to determine whether the adjusted model produces better results than the non-adjusted model.

Although the simulated phosphorus loads for the Duck Creek monitoring station were acceptable, a slight modification was made to improve the fit of the model. For the Duck Creek watershed data set, the phosphorus sorption coefficient (PSP) was changed from 0.39 to 0.44, and the phosphorus soil partitioning coefficient (PHOSKD) was changed from 185 to 235. These values were not changed for the other watersheds. This change effectively decreased the simulated TP load from all of the subwatersheds in the Duck Creek watershed, while maintaining a similar proportion of dissolved phosphorus. Again, the model was not re-evaluated because the model had already been shown to be valid.

Model Results After Adjustments

As shown in Table 3-3, the relative differences between simulated and observed event loads were improved with the revised model. The monthly NSCE statistic improved from 0.59 to 0.72 for SS at the East River site, and the total relative difference improved from 45.6% to 20.5%. The monthly NSCE statistic improved slightly from 0.64 to 0.66 for TP at the Duck Creek site, and the total relative difference improved from 25.5% to 5.6%. The simulated SS load at the East River site improved in 2004 and 2005, but was still substantially higher than the observed load in 2005 (Table 3-4).

A better understanding of the reasons for discrepancies between the observed and simulated flow and SS or TP loads would be helpful. Clues were found which might explain some of these discrepancies, but limited resources and the primary objective of this project did not permit further investigation.

Table B-3. Simulated and Observed Monthly Flow, Suspended Sediment, and Total Phosphorus Statistics for WY 2004-05. Simulated results based on adjusted LFR calibration parameters*. Relative differences are for the entire period.

Stream	Flow			Suspended Sediment			Total Phosphorus		
	R^2	NSCE	% Diff.	R^2	NSCE	% Diff.	R^2	NSCE	% Diff.
Apple	0.86	0.86	6.3%	0.87	0.77	-21.7%	0.81	0.81	-3.6%
Ashwaubenon	0.90	0.85	26.1%	0.69	0.69	1.9%	0.82	0.82	-3.1%
Baird	0.84	0.83	16.6%	0.66	0.65	-3.7%	0.70	0.66	-0.9%
Duck*	0.86	0.83	-12.8%	0.75	0.73	3.9%	0.66	0.66	5.6%
East River*	0.94	0.93	-8.0%	0.74	0.72	20.7%	0.86	0.86	7.6%

Table B-4. Annual Simulated and Observed Stream Flow, Suspended Sediment, and Total Phosphorus Yields in 2004 and 2005. Simulated results based on adjusted LFR calibration parameters*.

Stream	Flow (mm)				Suspended Sediment (t/ha)				Phosphorus (kg/ha)			
	2004		2005		2004		2005		2004		2005	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Apple	322	346	141	146	0.93	0.66	0.12	0.16	1.89	1.81	0.57	0.57
Ashwaubenon	272	345	108	133	0.69	0.70	0.20	0.21	1.99	1.97	0.78	0.71
Baird	364	403	107	146	0.73	0.67	0.10	0.13	2.34	2.15	0.50	0.67
Duck*	344	323	140	98	0.36	0.38	0.11	0.11	1.29	1.48	0.57	0.48
East River*	339	322	173	150	0.49	0.52	0.06	0.15	1.63	1.61	0.46	0.64

APPENDIX C

DEVELOPMENT OF THE OPTIMIZATION MODEL

Overview of the Optimization Model

Linear programming (LP) optimization models are often used to find "what ought to be" type solutions. That is, given certain set of conditions, LP models are used to find the best outcomes for those conditions. In this demonstration project, we are trying to find the least (minimum) cost combination of pollutant reduction scenarios that will meet a prescribed level of phosphorus loading, or alternatively the lowest (minimum) level of phosphorous loading that can be achieved within a given budget. In general LP models consist of four basic components: decision variables, parameters, an objective function, and constraints.

The decision variables are the choices that will be made within the model that reflect the decisions that are to be made within the Watershed; for example, which BMPs to apply and for what areal extent. Decision variables can be continuous, that is they can take on any value between a lower (e.g., 0%) and upper bound (e.g., 100%). In our model, we also use decision variables that can only be integers, either 0 or 1. These represent the choice of a BMP combination to apply, the decision variable will be 0 if that BMP Combination is not chosen in the optimal solution, and 1 if it is. In this case the LP would be classified as a mixed-integer programming model, as it contains both continuous and integer decision variables. Decision variables are the unknowns that are solved for within the model.

Parameters define the situation; for example, the costs per area for application of the BMPs, the allowable application area for specific BMPs, the coefficients in the regression equations described above, and which BMPs comprise the specific BMP Combinations. Parameters are user specified and are known.

The objective function combines decision variables and relevant parameters into the expression to be optimized (maximized or minimized).

The constraints provide realistic limits on the optimization and are expressed as equations or inequalities; for example, the total amount of land where mulch tillage can be applied must be less than or equal to (<=) a given parameter for the total application area for specific BMPs, or the total cost for all BMPs applied must be less than or equal to (<=) a given budget.

An example of how these are combined in an optimization model follows (note: the application of a BMP in the SWAT model runs is given as a percent or proportion (from 0 to 1); therefore the product of the percent applied times total allowable application area for a specific BMP gives the areal extent of application):

The objective function - Minimize Total Costs:

> Minimize Z = The Sum of the products of the Parameter (cost/area for application of a BMP) times the Decision Variable (the percent application a specific BMP) times the Parameter (the total application area for the specific BMP)[1].

Subject to the following constraints:

[1] This is a linear function as we are multiplying two parameters together (which will yield another parameter) and then multiplying this times the variable. For example. 2*5*X is the linear expression 10*X

Constraints on the application of any BMP:

The Decision Variable (the percent application a specific BMP) * Parameter (the total application area for the specific BMP) <= Parameter (the allowable application area for specific BMPs)

(One inequality of this type needs to be given for each type of BMP)

Constraints that link the application of a BMP with the phosphorus effluent that would result:

An example would be the regression equation described above for the BMP Regime "MT_VBS_DairyP":

Total Phosphorus (kg) for "MT_VBS_DairyP" = 5642.34 (kg) -10.27 (kg/Percent) * MT (percent) - 3.94 (kg/Percent) * DairyP (percent)

Total Phosphorus (kg) for "MT_VBS_DairyP", MT(percent), VBS(percent) and DairyP(percent) are all decision variables, their coefficients are parameters.

(one equality of this type needs to be given for each type of BMP Regime)

A constraint that limits the Total Phosphorous effluent for the study area:

Sum over all BMP types and over all BMP Regimes the Decision Variables "Total Phosphorus (kg) for each BMP Regime" <= Parameter ("Phosphorus Effluent Threshold")

(There is one constraint of this type)

A definition of the decision variables and parameters would then generally follow.

The optimal solution of the model will provide the values of all the decision variables (which BMP combinations were chosen, and to what areal extent each of the BMPs within those combinations were applied), as well as the cost of reaching the given phosphorus threshold. Models of this type can be solved by any number of available mixed-integer optimization packages. The CPLEX solver within AIMMS was used to set up, solve, and display - in a user interactive environment - the output for this research and demonstration optimization project. Other solvers are readily available. Excel comes with its own solver (called Solver), it can be used to solve optimization problems that are generally not too large or complex; an add-in is available to solve larger or more complex problems. The complete formulation of the optimization model is given in the next section. The results of using the optimization model to screen for the 10 best management practices to reduce total phosphorus in the test study area to approximately 50% of the base case value then follows.

Formulation of the Optimization Model

The optimization model was designed to choose the best combination of BMP combinations, and the application amounts of each requisite BMP within those combinations to either: (1) minimize cost given a maximum allowable phosphorus load, or (2) minimize the phosphorus load given a budget. Two main sources of data (model parameters) are required, the first is the expected reductions in Total Phosphorous given the application of BMPs in the test study area (this is provided by the multivariate regression equations), and the cost per unit associated with the application of the BMPs.

Formulation of the area source optimization model:

The objective functions:

Minimize Z1 = WeightForCost * sum(i,RegimeCost(i))
Z2 = (1 - WeightForCost) * sum(i, PProduction(i))

There are two objective functions:

Z1 = Minimizes the Total Costs occurred for applying BMPs in the test study area

Z2 = Minimizes the Total Phosphorus effluent from the test study area under the application of the BMPs.

Subject to the following constraints;

(2) BMP_In_Regime(i,j): X(i,j) <= Y(i)

The proportion of land to which a BMP in a BMP Regime can be applied must be less than the proportion of the study area to which the BMP Regime is applied. There is one constraint for each BMP type (j) and each BMP Regime type (i).

(3) Regime_selection(i): Y(i) <= z(i)

A BMP Regime cannot be applied to any portion of the study area unless it is chosen (i.e. z(i) = 1) within the optimal solution of the model. There is one constraint for each BMP Regime (i).

(4) Regime_proportion: sum(i, Y(i)) = 1

The sum of the proportions that the BMP Regimes are applied in the study area, must cover the entire study area (this includes the baseline, or do nothing, BMP Regime).

(5) BMP_area_constraint(j): sum(i, X(i,j)) <= BMPUpperBound(j)

The sum of all applications of BMP type (j) over all BMP Regimes cannot be greater than the upper bound amount (in percent) for BMP type (j). There is one constraint for each BMP type (j).

(6) BMPThresholdConstraint(i,j): X(i,j) >= BMPThreshold(i,j)*Z(i)

Assures that amount of the study area to which BMP type (j) in BMP Regime (i) is at least as large as the Threshold (this is either from the SWAT model runs or can be supplied by the user) if BMP Regime(i) is chosen to be applied in the optimal solution of the model (z(i) = 1). There is one constraint for each BMP type (j) and BMP Regime (i).

(7) CostConstraint: **TotalCost <= Budget + 100*Budget* WeightForCost**

Assures the total cost for all BMP applications is less than the total budget. This constraint is turned "on" if the Minimize Total Phosphorus effluent subject to a Budget Constraint model is chosen by the user.

(8) PhosphorousConstraint: **TotalPProduction <= PhosphorusThreshold + 100 * (1 - WeightForCost) * PhosphorusThreshold**

Assures the total Phosphorus effluent for all BMP applications is less than a user specified amount. This constraint is turned "on" if the Minimize Total Cost subject to a Phosphorus effluent Constraint model is chosen by the user.

(9) TillageConstraint(i): **X(i, *'CT'*) + X(i, *'MT'*) + X(i, *'ZT'*) = Y(i)**

Assures that the sum of the amount of land in Conventional Tillage, Mulch Tillage, or Zone Tillage in BMP Regime type (i) is equal to the total amount of land to which BMP Regime (i) is applied. There is one constraint for each BMP Regime (i).

(10) MT_ZT_Constraint: **Sum(i, X(i, *'MT'*) + X(i, *'ZT'*)) <= .60**

Assures that the sum of the amount of land in Mulch Tillage and Zone Tillage in the entire study area does not exceed 60% of the relevant study area. There is one constraint of this type.

(10) BMP_Matrix(i,j): **X(i,j) <= BMPtoRegimeMatrix(i,j)**

Links the BMP type to the BMP Regime types: the matrix contains a 1 if BMP type (j) is used in BMP Regime type (i) and 0 otherwise.

(11) Regime_LB_Constraint(i): **Y(i) >= User_Specified_Regime_LB(i)**

Assures that the total proportion of the study area to which BMP Regime(i) is applied is at least as large as the user specified lower bound.

(12) Regime_UB_Constraint(i): **Y(i) <= User_Specified_Regime_UB(i)**

Assures that the total amount of the study to which BMP Regime(i) is applied is no larger than the user specified Upper bound.

Parameters

RegressionIntercept(i) = the intercept for BMP Regime type (i) obtained from the multivariate regressions run on the SWAT model output.

RegressionCoefficient(i,j) = the coefficient of BMP type (j) in BMP Regime (i) obtained from the multivariate regressions run on the SWAT model output.

[Regression Intercept(i) and Coefficients(i,j) in Table 1, Appendix A]

WeightForCost = 1 if the model type Minimize Total Cost subject to a Phosphorus effluent Constraint is to be used, 0 if the model type Minimize Total Phosphorus effluent subject to a Budget Constraint is used in the optimization model.

TotalStudyArea(j) = the size of the study area in acres to which BMP type (j) can be applied.

[Total Study Area (j) in Table 2, Appendix A]

StudyArea = the total size of the study area in acres.

PhosphorusThreshold = the maximum amount of Phosphorus effluent allowed from the study area.

Budget = the total budget to be allocated to BMP activities in the study area

Budget_LB = The User specified lower bound on the total budget used in the trade-off analysis.

Budget_UB = The User specified upper bound on the total budget used in the trade-off analysis.

Phos_LB = The User specified lower bound on the total Phosphorus effluent used in the trade-off analysis.

Phos_UB = The User specified upper bound on the total Phosphorus effluent used in the trade-off analysis.

BMPtoRegimeMatrix(i,j) = 1 if BMP type (j) is used in BMP Regime (i), 0 otherwise

[BMP to Regime Matrix (i,j) in Table 3, Appendix A]

BMPUnitCost(i,j) = the cost per unit (percent or hectare) of the study area for the application of BMP type (j) in BMP Regime type (i).

[BMP Unit Costs per Acre given in Table 4, Appendix A]

User_Specified_Regime_UB(i) = The largest proportion of the study area (in percent or hectares) to which BMP Regime type (i) can be applied; this is chosen by the user and must be less than 1 (for percent) or the total size of the study area in hectares (the default value is 1).

User_Specified_Regime_LB(i) = The smallest proportion of the study area (in percent or hectares) to which BMP Regime type (i) must be applied; this is chosen by the user and must be greater than the User_Specified_Regime_LB(i) (the default value is 0).

BMPThreshold(i,j) = the minimum proportion of the area to which BMP type j in BMP Regime(i) must be applied if BMP Regime(i) is chosen for implementation in the model.

[BMP Thresholds (j) given in Table 5, Appendix A]

BMPUpperBound(j) = the maximum percent of the TotalStudyArea(j) that a BMP type (j) may be applied (default values for all (j) are set to 1).

Decision Variables

X(i,j) = The proportion of the study area to which BMP type (j) in BMP Regime (i) is chosen to be applied.

Y(i) = The proportion of the study area to which BMP Regime (i) is chosen within the model to be applied.

Z(i) = (1 if BMP Regime (i) is chosen to be applied to some portion of the study area, 0 otherwise)

RegimeCost(i) = sum(j, BMPUnitCost(i,j)*X(i,j)* TotalStudyArea(j))

Calculates the total cost occurred by the application of all BMPs type (j) in Regimes (i) in the study area.

TotalCost = sum (i,RegimeCost(i))

Calculates the total cost for all BMP Regime applications in the study area.

AreaBMPapplied(i,j) = X(i,j)*TotalStudyArea(j)

Calculates the total amount of land in acres to which BMP type (j) in BMP Regime (i) is applied.

AreaRegimeapplied(i) = Y(i)*StudyArea

Calculates the total amount of land in acres to which BMP Regime (i) is applied.

PProduction(i) =
RegressionIntercept(i)* Y(i) + sum (j,100*X(i,j) * RegressionCoefficient(i,j))

Applies the multiple regression equations obtained for each BMP Regime(i) from the SWAT model results. Calculates the phosphorous effluent that would result from the application of that BMP Regime

TotalPProduction = sum (i, PProduction(i))

Calculates the total phosphorus effluent from the study area.

APPENDIX D

SWAT BMP SCENARIO SIMULATION RESULTS FOR UPPER BOWER CREEK (LOWER FOX SUBWATERSHED LF01-15, 36 km^2, 1976-2000)

Agricultural BMP Scenarios	Total Phosphorus (kg)
100% Conventional Till;	5,927
100% Conventional Till, Dairy P reduced-100%;	5,507
100% Conventional Till, Stable soil P-100%;	5,040
100% Conventional Till, Stable/Lower Soil P-100%;	3,550
Conservation Tillage - 100% MT;	4,817
Conservation Tillage - 100% MT, Dairy P reduced-100%;	4,418
Conservation Tillage - 100% MT, Stable soil P-100%;	4,004
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%;	2,951
Conservation Tillage - 50% MT & 50% CT;	5,372
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%;	4,962
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%;	4,522
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%;	3,251
Conservation Tillage - 25% MT & 75% CT;	5,649
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%;	5,235
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%;	4,781
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%;	3,400
Conservation Tillage - 100% Zone-Till;	3,777
Conservation Tillage - 100% Zone-Till, Dairy P reduced-100%;	3,403
Conservation Tillage - 100% Zone-Till, Stable soil P-100%;	3,097
Conservation Tillage - 100% Zone-Till, Stable/Lower Soil P-100%;	2,468
Conservation Tillage - 50% ZT & 50% CT;	4,852
Conservation Tillage - 50% ZT & 50% CT, Dairy P reduced-100%;	4,455
Conservation Tillage - 50% ZT & 50% CT, Stable soil P-100%;	4,068
Conservation Tillage - 50% ZT & 50% CT, Stable/Lower Soil P-100%;	3,009
Conservation Tillage - 25% ZT & 75% CT;	5,389
Conservation Tillage - 25% ZT & 75% CT, Dairy P reduced-100%;	4,981
Conservation Tillage - 25% ZT & 75% CT, Stable soil P-100%;	4,554
Conservation Tillage - 25% ZT & 75% CT, Stable/Lower Soil P-100%;	3,279
100% Conventional Till; Manure Incorporated	5,539
100% Conventional Till, Dairy P reduced-100%; Manure Incorporated	5,215
100% Conventional Till, Stable soil P-100%; Manure Incorporated	4,820
100% Conventional Till, Stable/Lower Soil P-100%; Manure Incorporated	3,331
Conservation Tillage - 100% MT; Manure Incorporated	4,326

Agricultural BMP Scenarios	Total Phosphorus (kg)
Conservation Tillage - 100% MT, Dairy P reduced-100%; Manure Incorporated	4,042
Conservation Tillage - 100% MT, Stable soil P-100%; Manure Incorporated	3,716
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; Manure Incorporated	2,671
Conservation Tillage - 50% MT & 50% CT; Manure Incorporated	4,932
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; Manure Incorporated	4,629
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; Manure Incorporated	4,268
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; Manure Incorporated	3,001
Conservation Tillage - 25% MT & 75% CT; Manure Incorporated	5,236
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; Manure Incorporated	4,922
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; Manure Incorporated	4,544
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; Manure Incorporated	3,166
Conservation Tillage - 100% Zone-Till; Manure Incorporated	3,048
Conservation Tillage - 100% Zone-Till, Dairy P reduced-100%; Manure Incorporated	2,832
Conservation Tillage - 100% Zone-Till, Stable soil P-100%; Manure Incorporated	2,648
Conservation Tillage - 100% Zone-Till, Stable/Lower Soil P-100%; Manure Incorporated	2,049
Conservation Tillage - 50% ZT & 50% CT; Manure Incorporated	4,294
Conservation Tillage - 50% ZT & 50% CT, Dairy P reduced-100%; Manure Incorporated	4,024
Conservation Tillage - 50% ZT & 50% CT, Stable soil P-100%; Manure Incorporated	3,734
Conservation Tillage - 50% ZT & 50% CT, Stable/Lower Soil P-100%; Manure Incorporated	2,690
Conservation Tillage - 25% ZT & 75% CT; Manure Incorporated	4,916
Conservation Tillage - 25% ZT & 75% CT, Dairy P reduced-100%; Manure Incorporated	4,619
Conservation Tillage - 25% ZT & 75% CT, Stable soil P-100%; Manure Incorporated	4,277
Conservation Tillage - 25% ZT & 75% CT, Stable/Lower Soil P-100%; Manure Incorporated	3,011
100% Conventional Till; VBS (100%)	5,648
100% Conventional Till, Dairy P reduced-100%; VBS (100%)	5,243
100% Conventional Till, Stable soil P-100%; VBS (100%)	4,801
100% Conventional Till, Stable/Lower Soil P-100%; VBS (100%)	3,394
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

Agricultural BMP Scenarios	**Total Phosphorus (kg)**
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
Conservation Tillage - 100% Zone-Till; VBS (100%)	3,637
Conservation Tillage - 100% Zone-Till, Dairy P reduced-100%; VBS (100%)	3,274
Conservation Tillage - 100% Zone-Till, Stable soil P-100%; VBS (100%)	2,983
Conservation Tillage - 100% Zone-Till, Stable/Lower Soil P-100%; VBS (100%)	2,386
Conservation Tillage - 50% ZT & 50% CT; VBS (100%)	4,643
Conservation Tillage - 50% ZT & 50% CT, Dairy P reduced-100%; VBS (100%)	4,259
Conservation Tillage - 50% ZT & 50% CT, Stable soil P-100%; VBS (100%)	3,892
Conservation Tillage - 50% ZT & 50% CT, Stable/Lower Soil P-100%; VBS (100%)	2,890
Conservation Tillage - 25% ZT & 75% CT; VBS (100%)	5,145
Conservation Tillage - 25% ZT & 75% CT, Dairy P reduced-100%; VBS (100%)	4,751
Conservation Tillage - 25% ZT & 75% CT, Stable soil P-100%; VBS (100%)	4,346
Conservation Tillage - 25% ZT & 75% CT, Stable/Lower Soil P-100%; VBS (100%)	3,142
100% Conventional Till; VBS (100%) Manure Incorporated	5,280
100% Conventional Till, Dairy P reduced-100%; VBS (100%) Manure Incorporated	4,966
100% Conventional Till, Stable soil P-100%; VBS (100%) Manure Incorporated	4,592
100% Conventional Till, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated	3,187
Conservation Tillage - 100% MT; VBS (100%) Manure Incorporated	4,143
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%) Manure Incorporated	3,868
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%) Manure Incorporated	3,557
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated	2,569
Conservation Tillage - 50% MT & 50% CT; VBS (100%) Manure Incorporated	4,711
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%) Manure Incorporated	4,417
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%) Manure Incorporated	4,075
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated	2,878
Conservation Tillage - 25% MT & 75% CT; VBS (100%) Manure Incorporated	4,995
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%) Manure Incorporated	4,692
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%) Manure Incorporated	4,333
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated	3,032
Conservation Tillage - 100% Zone-Till; VBS (100%) Manure Incorporated	2,944

Agricultural BMP Scenarios	Total Phosphorus (kg)
Conservation Tillage - 100% Zone-Till, Dairy P reduced-100%; VBS (100%) Manure Incorporated	2,732
Conservation Tillage - 100% Zone-Till, Stable soil P-100%; VBS (100%) Manure Incorporated	2,556
Conservation Tillage - 100% Zone-Till, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated	1,987
Conservation Tillage - 50% ZT & 50% CT; VBS (100%) Manure Incorporated	4,112
Conservation Tillage - 50% ZT & 50% CT, Dairy P reduced-100%; VBS (100%) Manure Incorporated	3,849
Conservation Tillage - 50% ZT & 50% CT, Stable soil P-100%; VBS (100%) Manure Incorporated	3,574
Conservation Tillage - 50% ZT & 50% CT, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated	2,587
Conservation Tillage - 25% ZT & 75% CT; VBS (100%) Manure Incorporated	4,696
Conservation Tillage - 25% ZT & 75% CT, Dairy P reduced-100%; VBS (100%) Manure Incorporated	4,408
Conservation Tillage - 25% ZT & 75% CT, Stable soil P-100%; VBS (100%) Manure Incorporated	4,083
Conservation Tillage - 25% ZT & 75% CT, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated	2,887
Conservation Tillage - 100% MT; VBS (100%); CoverCrop(Silage)	4,345
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage)	3,971
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%); CoverCrop(Silage)	3,601
Conservation TIllage - 100% MT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage)	2,700
Conservation Tillage - 50% MT & 50% CT; VBS (100%); CoverCrop(Silage)	4,996
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage)	4,607
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage)	4,201
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage)	3,047
Conservation Tillage - 25% MT & 75% CT; VBS (100%); CoverCrop(Silage)	5,322
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage)	4,925
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage)	4,501
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage)	3,221
Conservation Tillage - 100% MT; VBS (100%); CoverCrop(Silage/Soybean)	4,119
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean)	3,769
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean)	3,429
Conservation TIllage - 100% MT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean)	2,576
Conservation Tillage - 50% MT & 50% CT; VBS (100%); CoverCrop(Silage/Soybean)	4,883
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean)	4,506
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean)	4,115
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean)	2,985
Conservation Tillage - 25% MT & 75% CT; VBS (100%); CoverCrop(Silage/Soybean)	5,265
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean)	4,875
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean)	4,458

Agricultural BMP Scenarios	Total Phosphorus (kg)
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean)	3,190
Conservation Tillage - 100% MT; Cover Crop (Silage)	4,534
Conservation Tillage - 100% MT, Dairy P reduced-100%; Cover Crop (Silage)	4,148
Conservation Tillage - 100% MT, Stable soil P-100%; Cover Crop (Silage)	3,759
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; Cover Crop (Silage)	2,807
Conservation Tillage - 50% MT & 50% CT; Cover Crop (Silage)	5,230
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; Cover Crop (Silage)	4,827
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; Cover Crop (Silage)	4,399
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; Cover Crop (Silage)	3,179
Conservation Tillage - 25% MT & 75% CT; Cover Crop (Silage)	5,578
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; Cover Crop (Silage)	5,167
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; Cover Crop (Silage)	4,720
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; Cover Crop (Silage)	3,364
Conservation Tillage - 100% MT; Cover Crop (Silage/Soybean)	4,294
Conservation Tillage - 100% MT, Dairy P reduced-100%; Cover Crop (Silage/Soybean)	3,933
Conservation Tillage - 100% MT, Stable soil P-100%; Cover Crop (Silage/Soybean)	3,576
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean)	2,676
Conservation Tillage - 50% MT & 50% CT; Cover Crop (Silage/Soybean)	5,110
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; Cover Crop (Silage/Soybean)	4,720
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; Cover Crop (Silage/Soybean)	4,308
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean)	3,113
Conservation Tillage - 25% MT & 75% CT; Cover Crop (Silage/Soybean)	5,518
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; Cover Crop (Silage/Soybean)	5,114
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; Cover Crop (Silage/Soybean)	4,674
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean)	3,332
Conservation Tillage - 100% MT; VBS (100%); CoverCrop(Silage) Manure-Incorp.	3,879
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.	3,617
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.	3,334
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.	2,451
Conservation Tillage - 50% MT & 50% CT; VBS (100%); CoverCrop(Silage) Manure-Incorp.	4,579
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.	4,292
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.	3,963
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.	2,819
Conservation Tillage - 25% MT & 75% CT; VBS (100%); CoverCrop(Silage) Manure-Incorp.	4,929

Agricultural BMP Scenarios	Total Phosphorus (kg)
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.	4,629
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.	4,277
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.	3,003
Conservation Tillage - 100% MT; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	3,713
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	3,461
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	3,199
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	2,360
Conservation Tillage - 50% MT & 50% CT; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	4,496
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	4,214
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	3,895
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	2,773
Conservation Tillage - 25% MT & 75% CT; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	4,888
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	4,590
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	4,243
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.	2,980
Conservation Tillage - 100% MT; Cover Crop (Silage) Manure-Incorp.	4,044
Conservation Tillage - 100% MT, Dairy P reduced-100%; Cover Crop (Silage) Manure-Incorp.	3,776
Conservation Tillage - 100% MT, Stable soil P-100%; Cover Crop (Silage) Manure-Incorp.	3,478
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; Cover Crop (Silage) Manure-Incorp.	2,546
Conservation Tillage - 50% MT & 50% CT; Cover Crop (Silage) Manure-Incorp.	4,792
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; Cover Crop (Silage) Manure-Incorp.	4,495
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; Cover Crop (Silage) Manure-Incorp.	4,149
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; Cover Crop (Silage) Manure-Incorp.	2,939
Conservation Tillage - 25% MT & 75% CT; Cover Crop (Silage) Manure-Incorp.	5,165
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; Cover Crop (Silage) Manure-Incorp.	4,855
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; Cover Crop (Silage) Manure-Incorp.	4,484
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; Cover Crop (Silage) Manure-Incorp.	3,135
Conservation Tillage - 100% MT; Cover Crop (Silage/Soybean) Manure-Incorp.	3,868
Conservation Tillage - 100% MT, Dairy P reduced-100%; Cover Crop (Silage/Soybean) Manure-Incorp.	3,610
Conservation Tillage - 100% MT, Stable soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.	3,334
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.	2,449
Conservation Tillage - 50% MT & 50% CT; Cover Crop (Silage/Soybean) Manure-Incorp.	4,703
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; Cover Crop (Silage/Soybean) Manure-Incorp.	4,413
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.	4,077

Agricultural BMP Scenarios	Total Phosphorus (kg)
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.	2,890
Conservation Tillage - 25% MT & 75% CT; Cover Crop (Silage/Soybean) Manure-Incorp.	5,121
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; Cover Crop (Silage/Soybean) Manure-Incorp.	4,814
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.	4,448
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.	3,111
100% Conventional Till; BioFuel	5,604
100% Conventional Till, Dairy P reduced-100%; BioFuel	5,185
100% Conventional Till, Stable soil P-100%; BioFuel	4,738
100% Conventional Till, Stable/Lower Soil P-100%; BioFuel	3,366
Conservation Tillage - 100% MT; BioFuel	4,621
Conservation Tillage - 100% MT, Dairy P reduced-100%; BioFuel	4,222
Conservation Tillage - 100% MT, Stable soil P-100%; BioFuel	3,825
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; BioFuel	2,841
Conservation Tillage - 50% MT & 50% CT; BioFuel	5,113
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; BioFuel	4,703
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; BioFuel	4,281
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; BioFuel	3,103
Conservation Tillage - 25% MT & 75% CT; BioFuel	5,359
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; BioFuel	4,944
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; BioFuel	4,510
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; BioFuel	3,235
Conservation Tillage - 100% Zone-Till; BioFuel	3,660
Conservation Tillage - 100% Zone-Till, Dairy P reduced-100%; BioFuel	3,286
Conservation Tillage - 100% Zone-Till, Stable soil P-100%; BioFuel	2,990
Conservation Tillage - 100% Zone-Till, Stable/Lower Soil P-100%; BioFuel	2,394
Conservation Tillage - 50% ZT & 50% CT; BioFuel	4,632
Conservation Tillage - 50% ZT & 50% CT, Dairy P reduced-100%; BioFuel	4,235
Conservation Tillage - 50% ZT & 50% CT, Stable soil P-100%; BioFuel	3,864
Conservation Tillage - 50% ZT & 50% CT, Stable/Lower Soil P-100%; BioFuel	2,880
Conservation Tillage - 25% ZT & 75% CT; BioFuel	5,118
Conservation Tillage - 25% ZT & 75% CT, Dairy P reduced-100%; BioFuel	4,710
Conservation Tillage - 25% ZT & 75% CT, Stable soil P-100%; BioFuel	4,301
Conservation Tillage - 25% ZT & 75% CT, Stable/Lower Soil P-100%; BioFuel	3,123
100% Conventional Till; Manure-Incorp.; BioFuel	5,217

Agricultural BMP Scenarios	Total Phosphorus (kg)
100% Conventional Till, Dairy P reduced-100%; Manure-Incorp.; BioFuel	4,893
100% Conventional Till, Stable soil P-100%; Manure-Incorp.; BioFuel	4,518
100% Conventional Till, Stable/Lower Soil P-100%; Manure-Incorp.; BioFuel	3,147
Conservation Tillage - 100% MT; Manure-Incorp.; BioFuel	4,129
Conservation Tillage - 100% MT, Dairy P reduced-100%; Manure-Incorp.; BioFuel	3,846
Conservation Tillage - 100% MT, Stable soil P-100%; Manure-Incorp.; BioFuel	3,537
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; Manure-Incorp.; BioFuel	2,561
Conservation Tillage - 50% MT & 50% CT; Manure-Incorp.; BioFuel	4,673
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; Manure-Incorp.; BioFuel	4,369
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; Manure-Incorp.; BioFuel	4,027
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; Manure-Incorp.; BioFuel	2,854
Conservation Tillage - 25% MT & 75% CT; Manure-Incorp.; BioFuel	4,945
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; Manure-Incorp.; BioFuel	4,631
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; Manure-Incorp.; BioFuel	4,273
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; Manure-Incorp.; BioFuel	3,001
Conservation Tillage - 100% Zone-Till; Manure-Incorp.; BioFuel	2,932
Conservation Tillage - 100% Zone-Till, Dairy P reduced-100%; Manure-Incorp.; BioFuel	2,716
Conservation Tillage - 100% Zone-Till, Stable soil P-100%; Manure-Incorp.; BioFuel	2,542
Conservation Tillage - 100% Zone-Till, Stable/Lower Soil P-100%; Manure-Incorp.; BioFuel	1,975
Conservation Tillage - 50% ZT & 50% CT; Manure-Incorp.; BioFuel	4,074
Conservation Tillage - 50% ZT & 50% CT, Dairy P reduced-100%; Manure-Incorp.; BioFuel	3,804
Conservation Tillage - 50% ZT & 50% CT, Stable soil P-100%; Manure-Incorp.; BioFuel	3,530
Conservation Tillage - 50% ZT & 50% CT, Stable/Lower Soil P-100%; Manure-Incorp.; BioFuel	2,561
Conservation Tillage - 25% ZT & 75% CT; Manure-Incorp.; BioFuel	4,645
Conservation Tillage - 25% ZT & 75% CT, Dairy P reduced-100%; Manure-Incorp.; BioFuel	4,349
Conservation Tillage - 25% ZT & 75% CT, Stable soil P-100%; Manure-Incorp.; BioFuel	4,024
Conservation Tillage - 25% ZT & 75% CT, Stable/Lower Soil P-100%; Manure-Incorp.; BioFuel	2,854
100% Conventional Till; VBS (100%): BioFuel	5,344
100% Conventional Till, Dairy P reduced-100%; VBS (100%): BioFuel	4,940
100% Conventional Till, Stable soil P-100%; VBS (100%): BioFuel	4,517
100% Conventional Till, Stable/Lower Soil P-100%; VBS (100%): BioFuel	3,221
Conservation Tillage - 100% MT; VBS (100%): BioFuel	4,426
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%): BioFuel	4,040
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%): BioFuel	3,663

Agricultural BMP Scenarios	**Total Phosphorus (kg)**
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; VBS (100%): BioFuel	2,731
Conservation Tillage - 50% MT & 50% CT; VBS (100%): BioFuel	4,885
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%): BioFuel	4,490
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%): BioFuel	4,090
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%): BioFuel	2,976
Conservation Tillage - 25% MT & 75% CT; VBS (100%): BioFuel	5,115
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%): BioFuel	4,715
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%): BioFuel	4,304
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%): BioFuel	3,099
Conservation Tillage - 100% Zone-Till; VBS (100%): BioFuel	3,527
Conservation Tillage - 100% Zone-Till, Dairy P reduced-100%; VBS (100%): BioFuel	3,164
Conservation Tillage - 100% Zone-Till, Stable soil P-100%; VBS (100%): BioFuel	2,881
Conservation Tillage - 100% Zone-Till, Stable/Lower Soil P-100%; VBS (100%): BioFuel	2,316
Conservation Tillage - 50% ZT & 50% CT; VBS (100%): BioFuel	4,436
Conservation Tillage - 50% ZT & 50% CT, Dairy P reduced-100%; VBS (100%): BioFuel	4,052
Conservation Tillage - 50% ZT & 50% CT, Stable soil P-100%; VBS (100%): BioFuel	3,699
Conservation Tillage - 50% ZT & 50% CT, Stable/Lower Soil P-100%; VBS (100%): BioFuel	2,769
Conservation Tillage - 25% ZT & 75% CT; VBS (100%): BioFuel	4,890
Conservation Tillage - 25% ZT & 75% CT, Dairy P reduced-100%; VBS (100%): BioFuel	4,496
Conservation Tillage - 25% ZT & 75% CT, Stable soil P-100%; VBS (100%): BioFuel	4,108
Conservation Tillage - 25% ZT & 75% CT, Stable/Lower Soil P-100%; VBS (100%): BioFuel	2,995
100% Conventional Till; VBS (100%) Manure Incorporated: BioFuel	4,976
100% Conventional Till, Dairy P reduced-100%; VBS (100%) Manure Incorporated: BioFuel	4,663
100% Conventional Till, Stable soil P-100%; VBS (100%) Manure Incorporated: BioFuel	4,308
100% Conventional Till, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated: BioFuel	3,014
Conservation Tillage - 100% MT; VBS (100%) Manure Incorporated: BioFuel	3,958
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%) Manure Incorporated: BioFuel	3,683
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%) Manure Incorporated: BioFuel	3,389
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated: BioFuel	2,465
Conservation Tillage - 50% MT & 50% CT; VBS (100%) Manure Incorporated: BioFuel	4,467
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%) Manure Incorporated: BioFuel	4,173
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%) Manure Incorporated: BioFuel	3,848
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated: BioFuel	2,739
Conservation Tillage - 25% MT & 75% CT; VBS (100%) Manure Incorporated: BioFuel	4,722

Agricultural BMP Scenarios	Total Phosphorus (kg)
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%) Manure Incorporated: BioFuel	4,418
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%) Manure Incorporated: BioFuel	4,078
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated: BioFuel	2,877
Conservation Tillage - 100% Zone-Till; VBS (100%) Manure Incorporated: BioFuel	2,833
Conservation Tillage - 100% Zone-Till, Dairy P reduced-100%; VBS (100%) Manure Incorporated: BioFuel	2,621
Conservation Tillage - 100% Zone-Till, Stable soil P-100%; VBS (100%) Manure Incorporated: BioFuel	2,455
Conservation Tillage - 100% Zone-Till, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated: BioFuel	1,917
Conservation Tillage - 50% ZT & 50% CT; VBS (100%) Manure Incorporated: BioFuel	3,905
Conservation Tillage - 50% ZT & 50% CT, Dairy P reduced-100%; VBS (100%) Manure Incorporated: BioFuel	3,642
Conservation Tillage - 50% ZT & 50% CT, Stable soil P-100%; VBS (100%) Manure Incorporated: BioFuel	3,382
Conservation Tillage - 50% ZT & 50% CT, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated: BioFuel	2,465
Conservation Tillage - 25% ZT & 75% CT; VBS (100%) Manure Incorporated: BioFuel	4,441
Conservation Tillage - 25% ZT & 75% CT, Dairy P reduced-100%; VBS (100%) Manure Incorporated: BioFuel	4,153
Conservation Tillage - 25% ZT & 75% CT, Stable soil P-100%; VBS (100%) Manure Incorporated: BioFuel	3,845
Conservation Tillage - 25% ZT & 75% CT, Stable/Lower Soil P-100%; VBS (100%) Manure Incorporated: BioFuel	2,740
Conservation Tillage - 100% MT; VBS (100%); CoverCrop(Silage): BioFuel	4,160
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage): BioFuel	3,786
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%); CoverCrop(Silage): BioFuel	3,433
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage): BioFuel	2,596
Conservation Tillage - 50% MT & 50% CT; VBS (100%); CoverCrop(Silage): BioFuel	4,752
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage): BioFuel	4,363
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage): BioFuel	3,975
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage): BioFuel	2,909
Conservation Tillage - 25% MT & 75% CT; VBS (100%); CoverCrop(Silage): BioFuel	5,048
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage): BioFuel	4,652
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage): BioFuel	4,246
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage): BioFuel	3,065
Conservation Tillage - 100% MT; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	3,934
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	3,584
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	3,260
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	2,472
Conservation Tillage - 50% MT & 50% CT; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	4,639
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	4,262
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	3,889

Agricultural BMP Scenarios	Total Phosphorus (kg)
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	2,847
Conservation Tillage - 25% MT & 75% CT; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	4,992
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	4,601
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	4,203
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean): BioFuel	3,034
Conservation Tillage - 100% MT; Cover Crop (Silage): BioFuel	4,338
Conservation Tillage - 100% MT, Dairy P reduced-100%; Cover Crop (Silage): BioFuel	3,951
Conservation Tillage - 100% MT, Stable soil P-100%; Cover Crop (Silage): BioFuel	3,580
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; Cover Crop (Silage): BioFuel	2,697
Conservation Tillage - 50% MT & 50% CT; Cover Crop (Silage): BioFuel	4,971
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; Cover Crop (Silage): BioFuel	4,568
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; Cover Crop (Silage): BioFuel	4,159
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; Cover Crop (Silage): BioFuel	3,031
Conservation Tillage - 25% MT & 75% CT; Cover Crop (Silage): BioFuel	5,288
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; Cover Crop (Silage): BioFuel	4,877
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; Cover Crop (Silage): BioFuel	4,449
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; Cover Crop (Silage): BioFuel	3,199
Conservation Tillage - 100% MT; Cover Crop (Silage/Soybean): BioFuel	4,098
Conservation Tillage - 100% MT, Dairy P reduced-100%; Cover Crop (Silage/Soybean): BioFuel	3,736
Conservation Tillage - 100% MT, Stable soil P-100%; Cover Crop (Silage/Soybean): BioFuel	3,397
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean): BioFuel	2,565
Conservation Tillage - 50% MT & 50% CT; Cover Crop (Silage/Soybean): BioFuel	4,851
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; Cover Crop (Silage/Soybean): BioFuel	4,461
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; Cover Crop (Silage/Soybean): BioFuel	4,067
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean): BioFuel	2,966
Conservation Tillage - 25% MT & 75% CT; Cover Crop (Silage/Soybean): BioFuel	5,228
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; Cover Crop (Silage/Soybean): BioFuel	4,823
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; Cover Crop (Silage/Soybean): BioFuel	4,403
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean): BioFuel	3,166
Conservation Tillage - 100% MT; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	3,694
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	3,432
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	3,165
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	2,347
Conservation Tillage - 50% MT & 50% CT; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	4,335

Agricultural BMP Scenarios	Total Phosphorus (kg)
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	4,048
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	3,737
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	2,681
Conservation Tillage - 25% MT & 75% CT; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	4,656
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	4,355
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	4,022
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage) Manure-Incorp.: BioFuel	2,847
Conservation Tillage - 100% MT; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	3,528
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	3,276
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	3,030
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	2,256
Conservation Tillage - 50% MT & 50% CT; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	4,252
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	3,970
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	3,669
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	2,635
Conservation Tillage - 25% MT & 75% CT; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	4,614
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	4,316
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	3,988
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%); CoverCrop(Silage/Soybean) Manure-Incorp.: BioFuel	2,824
Conservation Tillage - 100% MT; Cover Crop (Silage) Manure-Incorp.: BioFuel	3,848
Conservation Tillage - 100% MT, Dairy P reduced-100%; Cover Crop (Silage) Manure-Incorp.: BioFuel	3,580
Conservation Tillage - 100% MT, Stable soil P-100%; Cover Crop (Silage) Manure-Incorp.: BioFuel	3,299
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; Cover Crop (Silage) Manure-Incorp.: BioFuel	2,435
Conservation Tillage - 50% MT & 50% CT; Cover Crop (Silage) Manure-Incorp.: BioFuel	4,532
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; Cover Crop (Silage) Manure-Incorp.: BioFuel	4,236
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; Cover Crop (Silage) Manure-Incorp.: BioFuel	3,908
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; Cover Crop (Silage) Manure-Incorp.: BioFuel	2,791
Conservation Tillage - 25% MT & 75% CT; Cover Crop (Silage) Manure-Incorp.: BioFuel	4,874
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; Cover Crop (Silage) Manure-Incorp.: BioFuel	4,565
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; Cover Crop (Silage) Manure-Incorp.: BioFuel	4,213
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; Cover Crop (Silage) Manure-Incorp.: BioFuel	2,969
Conservation Tillage - 100% MT; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	3,672
Conservation Tillage - 100% MT, Dairy P reduced-100%; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	3,414
Conservation Tillage - 100% MT, Stable soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	3,155

Agricultural BMP Scenarios	Total Phosphorus (kg)
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	2,338
Conservation Tillage - 50% MT & 50% CT; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	4,444
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	4,153
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	3,836
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	2,743
Conservation Tillage - 25% MT & 75% CT; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	4,830
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	4,523
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	4,177
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; Cover Crop (Silage/Soybean) Manure-Incorp.: BioFuel	2,945

APPENDIX E

STEP-BY-STEP APPLICATION OF OPTIMOD

Table E-1 illustrates how SWAT output data (from **Error! Reference source not found.**) was re-organized in preparation for multivariate regression analysis. For example, one of the BMP scenarios in **Error! Reference source not found.** 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. The multivariate regressions were all run in Excel. The regression results for the BMP scenario named "MT_VBS_DairyP" are provided in Table E-2.

Table E-1. Preparation of SWAT Output Data for Multivariate Regression Analysis

% BMP Application (includes 100% VBS)		Total Phosphorus (kg)		
MT (%)	DP/StableP/StableLowerP (%)	DP	STABLE_P	STABLE_LOWER_P
100	0	4,611	4,611	4,611
100	100	4,225	3,832	2,835
50	0	5,129	5,129	5,129
50	100	4,734	4,316	3,115
25	0	5,388	5,388	5,388
25	100	4,989	4,558	3,254

The "R Square" (in Table E-2) is a measure of the goodness of the linear fit of the input data (percent MT and Dairy P, with VBS at 100%) to SWAT output (i.e., simulated total phosphorus loading). Values near 0 suggest a linear model does not fit the input data well, while values close to 1 suggest that a linear model fits the data very well, as is the case with this example. The regression results indicate that there is a linear response between SWAT simulated total phosphorus loading and the percent MT applied and the percent DairyP applied, with 100% application of VBS. SWAT simulations for the "MT_VBS_DairyP" scenario can then be represented in the optimization model with the following linear equation:

$$TotalPhosphorus(kg) = 5642.34(kg) - 10.27(kg / percent) * MT(percent) - 3.94(kg / percent) * DairyP(percent)$$

This equation approximates how SWAT simulated phosphorus load will respond to the application of the specific BMPs in this scenario. This equation tells us that for each percent increase in the application of mulch tillage, the total phosphorus load decreases by 10.27 kg; and for each percent increase in the application of reduced phosphorus in dairy cow feed, the total phosphorus load decreases by 3.94 kg. Linear response equations were developed for all of the BMP scenarios results simulated by SWAT. These equations were then used in OptiMod.

The linear regression equations are approximations of SWAT output and likely incur some error. The "Residuals" in **Error! Not a valid bookmark self-reference.** Table E-2 measure the error associated with the difference between SWAT simulations and the multivariate regression equation results. For the BMP scenario in **Error! Not a valid bookmark self-reference.** Table E-2, the error is quite small (less than 1/10 of 1% at all input data values). The full set of regression results for all of the BMP scenarios have over 96% of the residuals within 5% of the true input value; the largest residual error is 14%. These error levels are small enough; therefore, all of the regression equations were used in OptiMod.

Table E-2. Multivariate Regression Results for "MT_VBS_DairyP"

SUMMARY OUTPUT	***MT_VBS_DairyP***				
Regression Statistics					
Multiple R	0.999972748				
R Square	0.999945497				
Adjusted R Square	0.999909161				
Standard Error	3.93				
Observations	6				
ANOVA					
	df	***SS***	***MS***	***F***	***Significance F***
Regression	2	848026.23	424013.12	27519.80	4.02E-07
Residual	3	46.22269927	15.41		
Total	5	848072.45			
	Coefficients	***Standard Error***	***t Stat***	***P-value***	
Intercept	5642.34	3.76	1501.37	6.51E-10	
MT	-10.27	0.05	-199.88	2.76E-07	
DP/StableP/StableLowerP	-3.94	0.03	-122.82	1.18E-06	
RESIDUAL OUTPUT					
Observation	***Predicted DP***	***Residuals***			
1	4615.08	-3.709654347			
2	4221.42	3.708174844			
3	5128.71	0.74373658			
4	4735.05	-0.739298071			
5	5385.53	2.965917766			
6	4991.86	-2.968876772			

With this set up, OptiMod can be used to test varying application amounts for the BMPs in the scenarios that may not have been simulated in SWAT. For example, the regression equation could give an estimated total phosphorus load for the combination of 35% application of mulch tillage, 78% application of reducing phosphorus in dairy feed, and 100% VBS. In this way, combinations of BMP scenarios, and their associated application levels, can be compared within OptiMod.

The regression results and OptiMod parameters for all of the BMP regimes from the SWAT model runs are presented in Tables F-3 through F-7. Following the these tables, a step-by-step application of OptiMod is presented.

Table E-3. Regression Intercept (i) and Coefficients (i,j)

Thresholds with amounts in Regimes *Regression Formulas*	Regression results	BMP (Coefficient in kg/percent land area										
BMP Regime	**Intercept (in kg)**	**CT**	**MT**	**ZT**	**DP**	**MAN INC**	**STABLE P**	**STABLE LOWER P**	**VBS**	**CvrCropSlge**	**CvrCropSlge(SOY)**	**BioFuel**
BASELINE	5926.55											
DairyP	5926.55				-4.19							
Stable P	5926.55						-8.87					
LowerStableP	5926.55							-23.76				
MT DairyP	5920.81		-10.99		-4.08							
MT Stable P	5905.16		-10.72				-8.44					
MT LowerStableP	5777.74		-8.54					-20.79				
ZT DairyP	5913.46			-21.27	-3.93							
ZT Stable P	5866.43			-20.46			-7.67					
ZT LowerStableP	5615.38			-16.16				-17.54				
DairyP ALLMAN	5538.83				-3.24							
Stable P ALLMAN	5538.83						-7.19					
LowerStableP ALLMAN	5538.83							-22.07				
MT DairyP ALLMAN	5527.07		-11.93		-3.00							
MT Stable P ALLMAN	5506.86		-11.59				-6.55					
MT Lower Stable P ALLMAN	5377.49		-9.37					-18.85				
ZT DairyP ALLMAN	5507.39			-24.37	-2.61							
ZT Stable P ALLMAN	5445.68			-23.31			-5.33					
ZT Lower Stable P ALLMAN	5186.58			-18.87				-15.03				
VBS DairyP	5647.54				-4.04				0.00			
VBS StableP	5647.54						-8.47		0.00			
VBS LowerStableP	5647.54							-22.53	0.00			
MT VBS DairyP	5642.34		-10.27		-3.94				0.00			
MT VBS StableP	5627.87		-10.02				-8.08		0.00			
MT VBS LowerStableP	5508.35		-7.98					-19.75	0.00			
ZT_VBS_DairyP	5635.58			-19.90	-3.80				0.00			
ZT_VBS_StableP	5591.52			-19.14			-7.35		0.00			
ZT VBS LowerStableP	5355.46			-15.09				-16.69	0.00			
VBS DairyP ALLMAN	5279.57				-3.13				0.00			
VBS StableP ALLMAN	5279.57						-6.88		0.00			
VBS LowerStableP ALLMAN	5279.57							-20.93	0.00			
MT VBS DairyP ALLMAN	5268.55		-11.18		-2.91				0.00			
MT_VBS_StableP_ALLMAN	5249.68		-10.85				-6.28		0.00			
MT_VBS_LowerStableP_ALLMAN	5128.32		-8.77					-17.90	0.00			
ZT_VBS_DairyP_ALLMAN	5249.99			-22.85	-2.54				0.00			
ZT_VBS_StableP_ALLMAN	5191.87			-21.86			-5.13		0.00			
ZT_VBS_LowerStableP_ALLMAN	4948.24			-17.68				-14.30	0.00			
MT_VBS_DairyP_CvrCropSlge	5638.66		-12.88		-3.86				0.00	0.00		
MT_VBS_StableP_CvrCropSlge	5617.37		-12.51				-7.87		0.00	0.00		
MT VBS LowerStableP CvrCropSlge	5470.00		-9.98					-18.98	0.00	0.00		
MT VBS DairyP CvrCropSlge(SOY)	5631.87		-15.02		-3.73				0.00		0.00	
MT VBS StableP CvrCropSlge(SOY)	5601.73		-14.50				-7.55		0.00		0.00	
MT VBS LowerStableP CvrCropSlge(SOY)	5440.36		-11.73					-18.39	0.00		0.00	
MT DairyP CvrCropSlge	5916.85		-13.76		-4.00					0.00		
MT StableP CvrCropSlge	5893.94		-13.37				-8.22			0.00		
MT LowerStableP CvrCropSlge	5736.92		-10.68					-19.97		0.00		
MT DairyP CvrCropSlge(SOY)	5909.67		-16.03		-3.86						0.00	
MT StableP CvrCropSlge(SOY)	5877.39		-15.48				-7.88				0.00	
MT LowerStableP CvrCropSlge(SOY)	5705.46		-12.53					-19.34			0.00	
MT VBS DairyP CvrCropSlge ALLMAN	5264.49		-13.75		-2.83							
MT VBS StableP CvrCropSlge ALLMAN	5237.72		-13.29				-6.04					
MT VBS LowerStableP CvrCropSlge ALLMAN	5085.50		-10.68					-17.05				
MT VBS DairyP CvrCropSlge(SOY) ALLMAN	5261.60		-15.36		-2.77							
MT VBS StableP CvrCropSlge(SOY) ALLMAN	5228.84		-14.80				-5.87					
MT VBS LowerStableP CvrCropSlge(SOY) ALLMAN	5063.71		-11.97					-16.61				
MT DairyP CvrCropSlge ALLMAN	5522.73		-14.67		-2.91							
MT StableP CvrCropSlge ALLMAN	5494.14		-14.18				-6.30					
MT LowerStableP CvrCropSlge ALLMAN	5332.03		-11.40					-17.94				
MT DairyP CvrCropSlge(SOY) ALLMAN	5519.66		-16.38		-2.85							
MT StableP CvrCropSlge(SOY) ALLMAN	5484.73		-15.78				-6.11					
MT LowerStableP CvrCropSlge(SOY) ALLMAN	5308.86		-12.77					-17.47				
BioFuel DairyP	5604.31				-4.19							0.00
BioFuel StableP	5604.31						-8.66					0.00
BioFuel LowerStableP	5604.31							-22.38				0.00
MT BioFuel DairyP	5598.56		-9.73		-4.08							0.00
MT BioFuel StableP	5583.96		-9.48				-8.25					0.00
MT BioFuel LowerStableP	5470.81		-7.54					-19.71				0.00
ZT BioFuel DairyP	5591.21			-19.21	-3.93							0.00
ZT BioFuel StableP	5547.31			-18.46			-7.52					0.00
ZT BioFuel LowerStableP	5320.93			-14.58				-16.72				0.00
BioFuel DairyP ALLMAN	5216.58				-3.24							0.00
BioFuel StableP ALLMAN	5216.58						-6.99					0.00
BioFuel LowerStableP ALLMAN	5216.58							-20.69				0.00
MT BioFuel DairyP ALLMAN	5204.82		-10.67		-3.00							0.00
MT BioFuel StableP ALLMAN	5185.66		-10.34				-6.37					0.00
MT BioFuel LowerStableP ALLMAN	5070.56		-8.37					-17.77				0.00
ZT BioFuel DairyP ALLMAN	5185.15			-22.31	-2.61							0.00
ZT_BioFuel_StableP_ALLMAN	5126.57			-21.31			-5.19					0.00
ZT_BioFuel_LowerStableP_ALLMAN	4892.14			-17.29				-14.20				
BioFuel_VBS__DairyP	5344.47				-4.04							
BioFuel_VBS__StableP	5344.47						-8.27					
BioFuel_VBS__LowerStableP	5344.47							-21.23				
MT_BioFuel_VBS__DairyP	5339.27		-9.09		-3.94							
MT_BioFuel_VBS__StableP	5325.77		-8.86				-7.90					
MT_BioFuel_VBS__LowerStableP	5219.64		-7.04					-18.73				
ZT_BioFuel_VBS__DairyP	5332.50			-17.97	-3.80							
ZT_BioFuel_VBS__StableP	5291.41			-17.27			-7.21					
ZT_BioFuel_VBS__LowerStableP	5078.54			-13.62				-15.91				
BioFuel_VBS__DairyP_ALLMAN	4976.49				-3.13							
BioFuel_VBS__StableP_ALLMAN	4976.49						-6.68					
BioFuel_VBS__LowerStableP_ALLMAN	4976.49							-19.63				
MT_BioFuel_VBS__DairyP_ALLMAN	4965.47		-9.99		-2.91							
MT_BioFuel_VBS__StableP_ALLMAN	4947.58		-9.69				-6.11					
MT_BioFuel_VBS__LowerStableP_ALLMAN	4839.61		-7.84					-16.89				
ZT_BioFuel_VBS__DairyP_ALLMAN	4946.91			-20.93	-2.54							
ZT_BioFuel_VBS__StableP_ALLMAN	4891.76			-19.98			-4.99					
ZT_BioFuel_VBS__LowerStableP_ALLMAN	4671.32			-16.20				-13.52				
MT_BioFuel_VBS_DairyP_CvrCropSlge	5335.58		-11.69		-3.86							
MT_BioFuel_VBS_StableP_CvrCropSlge	5315.27		-11.35				-7.69					
MT_BioFuel_VBS_LowerStableP_CvrCropSlge	5181.29		-9.05					-17.97				
MT_BioFuel_VBS_DairyP_CvrCropSlge(SOY)	5328.80		-13.84		-3.73							
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)	5299.64		-13.34				-7.38					
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)	5151.66		-10.80					-17.37				
MT_BioFuel_DairyP_CvrCropSlge	5594.60		-12.50		-4.00							
MT_BioFuel_StableP_CvrCropSlge	5572.73		-12.13				-8.03					
MT_BioFuel_LowerStableP_CvrCropSlge	5430.00		-9.68					-18.90				
MT_BioFuel_DairyP_CvrCropSlge(SOY)	5587.42		-14.77		-3.86							
MT_BioFuel_StableP_CvrCropSlge(SOY)	5556.19		-14.24				-7.70					
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)	5398.54		-11.54					-18.27				
MT_BioFuel_VBS_DairyP_CvrCropSlge_ALLMAN	4961.41		-12.57		-2.83							
MT_BioFuel_VBS_StableP_CvrCropSlge_ALLMAN	4935.62		-12.13				-5.87					
MT_BioFuel_VBS_LowerStableP_CvrCropSlge_ALLMAN	4796.79		-9.75					-16.03				
MT_BioFuel_VBS_DairyP_CvrCropSlge(SOY)_ALLMAN	4958.52		-14.18		-2.77							
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)_ALLMAN	4926.74		-13.64				-5.69					
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN	4775.00		-11.03					-15.60				
MT_BioFuel_DairyP_CvrCropSlge_ALLMAN	5200.49		-13.41		-2.92							
MT_BioFuel_StableP_CvrCropSlge_ALLMAN	5172.95		-12.94				-6.11					
MT_BioFuel_LowerStableP_CvrCropSlge_ALLMAN	5025.12		-10.40					-16.86				
MT_BioFuel_DairyP_CvrCropSlge(SOY)_ALLMAN	5197.42		-15.12		-2.85							
MT_BioFuel_StableP_CvrCropSlge(SOY)_ALLMAN	5163.53		-14.54				-5.93					
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)_ALLMAN	5001.93		-11.77					-16.40				

Table E-4: Total Study Area (j)

BMP	Areas (TotStudyArea(j)) Acres
CT	5363.88
MT	5363.88
ZT	5363.88
DP	5709.93
MAN_INC	951.66
STABLE_P	1816.80
STABLE_LOWER_P	4403.92
VBS	75.66
CvrCropSlge	951.66
CvrCropSlge(SOY)	1903.31
BioFuel	519.09

Table E-5. BMP to Scenarios Matrix (i,j)

BMPtoRegime

BMP Regime		CT	MT	ZT	DP	MAN_INC	STABLE_P	STABLE_LOWER_P	VBS	CvrCropSlge	CvrCropSlge(SOY)	BioFuel
BASELINE		1.00	0.00									
DairyP		1.00			1.00							
Stable_P		1.00					1.00					
LowerStableP		1.00						1.00				
MT_DairyP		1.00	1.00		1.00							
MT_Stable_P		1.00	1.00				1.00					
MT_LowerStableP		1.00	1.00					1.00				
ZT_DairyP		1.00		1.00	1.00							
ZT_Stable_P		1.00		1.00			1.00					
ZT_LowerStableP		1.00		1.00				1.00				
DairyP_ALLMAN		1.00			1.00	1.00						
Stable_P_ALLMAN		1.00				1.00	1.00					
LowerStableP_ALLMAN		1.00				1.00		1.00				
MT_DairyP_ALLMAN		1.00	1.00		1.00	1.00						
MT_Stable_P_ALLMAN		1.00	1.00			1.00	1.00					
MT_Lower_Stable_P_ALLMAN		1.00	1.00			1.00		1.00				
ZT_DairyP_ALLMAN		1.00		1.00	1.00	1.00						
ZT_Stable_P_ALLMAN		1.00		1.00		1.00	1.00					
ZT_Lower_Stable_P_ALLMAN		1.00		1.00		1.00		1.00				
VBS_DairyP		1.00			1.00				1.00			
VBS_StableP		1.00					1.00		1.00			
VBS_LowerStableP		1.00						1.00	1.00			
MT_VBS_DairyP		1.00	1.00		1.00				1.00			
MT_VBS_StableP		1.00	1.00				1.00		1.00			
MT_VBS_LowerStableP		1.00	1.00					1.00	1.00			
ZT_VBS_DairyP		1.00		1.00	1.00				1.00			
ZT_VBS_StableP		1.00		1.00			1.00		1.00			
ZT_VBS_LowerStableP		1.00		1.00				1.00	1.00			
VBS_DairyP_ALLMAN		1.00			1.00	1.00			1.00			
VBS_StableP_ALLMAN		1.00				1.00	1.00		1.00			
VBS_LowerStableP_ALLMAN		1.00				1.00		1.00	1.00			
MT_VBS_DairyP_ALLMAN		1.00	1.00		1.00	1.00			1.00			
MT_VBS_StableP_ALLMAN		1.00	1.00			1.00	1.00		1.00			
MT_VBS_LowerStableP_ALLMAN		1.00	1.00			1.00		1.00	1.00			
ZT_VBS_DairyP_ALLMAN		1.00		1.00	1.00	1.00			1.00			
ZT_VBS_StableP_ALLMAN		1.00		1.00		1.00	1.00		1.00			
ZT_VBS_LowerStableP_ALLMAN		1.00		1.00		1.00		1.00	1.00			
MT_VBS_DairyP_CvrCropSlge		1.00	1.00		1.00				1.00	1.00		
MT_VBS_StableP_CvrCropSlge		1.00	1.00				1.00		1.00	1.00		
MT_VBS_LowerStableP_CvrCropSlge		1.00	1.00					1.00	1.00	1.00		
MT_VBS_DairyP_CvrCropSlge(SOY)		1.00	1.00		1.00				1.00		1.00	
MT_VBS_StableP_CvrCropSlge(SOY)		1.00	1.00				1.00		1.00		1.00	
MT_VBS_LowerStableP_CvrCropSlge(SOY)		1.00	1.00					1.00	1.00		1.00	
MT_DairyP_CvrCropSlge		1.00	1.00		1.00					1.00		
MT_StableP_CvrCropSlge		1.00	1.00				1.00			1.00		
MT_LowerStableP_CvrCropSlge		1.00	1.00					1.00		1.00		
MT_DairyP_CvrCropSlge(SOY)		1.00	1.00		1.00						1.00	
MT_StableP_CvrCropSlge(SOY)		1.00	1.00				1.00				1.00	
MT_LowerStableP_CvrCropSlge(SOY)		1.00	1.00					1.00			1.00	
MT_VBS_DairyP_CvrCropSlge_ALLMAN		1.00	1.00		1.00	1.00			1.00	1.00		
MT_VBS_StableP_CvrCropSlge_ALLMAN		1.00	1.00			1.00	1.00		1.00	1.00		
MT_VBS_LowerStableP_CvrCropSlge_ALLMAN		1.00	1.00			1.00		1.00	1.00	1.00		
MT_VBS_DairyP_CvrCropSlge(SOY)_ALLMAN		1.00	1.00		1.00	1.00			1.00		1.00	
MT_VBS_StableP_CvrCropSlge(SOY)_ALLMAN		1.00	1.00			1.00	1.00		1.00		1.00	
MT_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN		1.00	1.00			1.00		1.00	1.00		1.00	
MT_DairyP_CvrCropSlge_ALLMAN		1.00	1.00		1.00	1.00				1.00		
MT_StableP_CvrCropSlge_ALLMAN		1.00	1.00			1.00	1.00			1.00		
MT_LowerStableP_CvrCropSlge_ALLMAN		1.00	1.00			1.00		1.00		1.00		
MT_DairyP_CvrCropSlge(SOY)_ALLMAN		1.00	1.00		1.00	1.00					1.00	
MT_StableP_CvrCropSlge(SOY)_ALLMAN		1.00	1.00			1.00	1.00				1.00	
MT_LowerStableP_CvrCropSlge(SOY)_ALLMAN		1.00	1.00			1.00		1.00			1.00	
BioFuel_DairyP		1.00			1.00							1.00
BioFuel_StableP		1.00					1.00					1.00
BioFuel_LowerStableP		1.00						1.00				1.00
MT_BioFuel_DairyP		1.00	1.00		1.00							1.00
MT_BioFuel_StableP		1.00	1.00				1.00					1.00
MT_BioFuel_LowerStableP		1.00	1.00					1.00				1.00
ZT_BioFuel_DairyP		1.00		1.00	1.00							1.00
ZT_BioFuel_StableP		1.00		1.00			1.00					1.00
ZT_BioFuel_LowerStableP		1.00		1.00				1.00				1.00
BioFuel_DairyP_ALLMAN		1.00			1.00	1.00						1.00
BioFuel_StableP_ALLMAN		1.00				1.00	1.00					1.00
BioFuel_LowerStableP_ALLMAN		1.00				1.00		1.00				1.00
MT_BioFuel_DairyP_ALLMAN		1.00	1.00		1.00	1.00						1.00
MT_BioFuel_StableP_ALLMAN		1.00	1.00			1.00	1.00					1.00
MT_BioFuel_LowerStableP_ALLMAN		1.00	1.00			1.00		1.00				1.00
ZT_BioFuel_DairyP_ALLMAN		1.00		1.00	1.00	1.00						1.00
ZT_BioFuel_StableP_ALLMAN		1.00		1.00		1.00	1.00					1.00
ZT_BioFuel_LowerStableP_ALLMAN		1.00		1.00		1.00		1.00				1.00
BioFuel_VBS__DairyP		1.00			1.00				1.00			1.00
BioFuel_VBS__StableP		1.00					1.00		1.00			1.00
BioFuel_VBS__LowerStableP		1.00						1.00	1.00			1.00
MT_BioFuel_VBS__DairyP		1.00	1.00		1.00				1.00			1.00
MT_BioFuel_VBS__StableP		1.00	1.00				1.00		1.00			1.00
MT_BioFuel_VBS__LowerStableP		1.00	1.00					1.00	1.00			1.00
ZT_BioFuel_VBS__DairyP		1.00		1.00	1.00				1.00			1.00
ZT_BioFuel_VBS__StableP		1.00		1.00			1.00		1.00			1.00
ZT_BioFuel_VBS__LowerStableP		1.00		1.00				1.00	1.00			1.00
BioFuel_VBS__DairyP_ALLMAN		1.00			1.00	1.00			1.00			1.00
BioFuel_VBS__StableP_ALLMAN		1.00				1.00	1.00		1.00			1.00
BioFuel_VBS__LowerStableP_ALLMAN		1.00				1.00		1.00	1.00			1.00
MT_BioFuel_VBS__DairyP_ALLMAN		1.00	1.00		1.00	1.00			1.00			1.00
MT_BioFuel_VBS__StableP_ALLMAN		1.00	1.00			1.00	1.00		1.00			1.00
MT_BioFuel_VBS__LowerStableP_ALLMAN		1.00	1.00			1.00		1.00	1.00			1.00
ZT_BioFuel_VBS__DairyP_ALLMAN		1.00		1.00	1.00	1.00			1.00			1.00
ZT_BioFuel_VBS__StableP_ALLMAN		1.00		1.00		1.00	1.00		1.00			1.00
ZT_BioFuel_VBS__LowerStableP_ALLMAN		1.00		1.00		1.00		1.00	1.00			1.00
MT_BioFuel_VBS_DairyP_CvrCropSlge		1.00	1.00		1.00				1.00	1.00		1.00
MT_BioFuel_VBS_StableP_CvrCropSlge		1.00	1.00				1.00		1.00	1.00		1.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge		1.00	1.00					1.00	1.00	1.00		1.00
MT_BioFuel_VBS_DairyP_CvrCropSlge(SOY)		1.00	1.00		1.00				1.00		1.00	1.00
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)		1.00	1.00				1.00		1.00		1.00	1.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)		1.00	1.00					1.00	1.00		1.00	1.00
MT_BioFuel_DairyP_CvrCropSlge		1.00	1.00		1.00					1.00		1.00
MT_BioFuel_StableP_CvrCropSlge		1.00	1.00				1.00			1.00		1.00
MT_BioFuel_LowerStableP_CvrCropSlge		1.00	1.00					1.00		1.00		1.00
MT_BioFuel_DairyP_CvrCropSlge(SOY)		1.00	1.00		1.00						1.00	1.00
MT_BioFuel_StableP_CvrCropSlge(SOY)		1.00	1.00				1.00				1.00	1.00
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)		1.00	1.00					1.00			1.00	1.00
MT_BioFuel_VBS_DairyP_CvrCropSlge_ALLMAN		1.00	1.00		1.00	1.00			1.00	1.00		1.00
MT_BioFuel_VBS_StableP_CvrCropSlge_ALLMAN		1.00	1.00			1.00	1.00		1.00	1.00		1.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge_ALLMAN		1.00	1.00			1.00		1.00	1.00	1.00		1.00
MT_BioFuel_VBS_DairyP_CvrCropSlge(SOY)_ALLMAN		1.00	1.00		1.00	1.00			1.00		1.00	1.00
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)_ALLMAN		1.00	1.00			1.00	1.00		1.00		1.00	1.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN		1.00	1.00			1.00		1.00	1.00		1.00	1.00
MT_BioFuel_DairyP_CvrCropSlge_ALLMAN		1.00	1.00		1.00	1.00				1.00		1.00

Table E-6. BMPUnitCost(i,j)

BMP Regime	Intercept (in kg)	CT	MT	ZT	DP	MAN INC	STABLE P	STABLE LOWER P	VBS	CvrCropSlge	CvrCropSlge(SOY)	BioFuel
Costs per Acre												
BMP Regime		CT	MT	ZT	DP	MAN INC	STABLE P	STABLE LOWER P	VBS	CvrCropSlge	CvrCropSlge(SOY)	BioFuel
BASELINE		0.00										
DairyP		0.00			0.00							
Stable P		0.00					28.00					
LowerStableP		0.00						60.00				
MT DairyP		0.00	15.00		0.00							
MT Stable P		0.00	15.00				28.00					
MT LowerStableP		0.00	15.00					60.00				
ZT DairyP		0.00		25.00	0.00							
ZT Stable P		0.00		25.00			28.00					
ZT LowerStableP		0.00		25.00				60.00				
DairyP ALLMAN		0.00			0.00	15.00						
Stable P ALLMAN		0.00				15.00	28.00					
LowerStableP ALLMAN		0.00				15.00		60.00				
MT DairyP ALLMAN		0.00	15.00		0.00	15.00						
MT Stable P ALLMAN		0.00	15.00			15.00	28.00					
MT Lower Stable P ALLMAN		0.00	15.00			15.00		60.00				
ZT DairyP ALLMAN		0.00		25.00	0.00	15.00						
ZT Stable P ALLMAN		0.00		25.00		15.00	28.00					
ZT Lower Stable P ALLMAN		0.00		25.00		15.00		60.00				
VBS DairyP		0.00			0.00				1300.00			
VBS StableP		0.00					28.00		1300.00			
VBS LowerStableP		0.00						60.00	1300.00			
MT VBS DairyP		0.00	15.00		0.00				1300.00			
MT VBS StableP		0.00	15.00				28.00		1300.00			
MT VBS LowerStableP		0.00	15.00					60.00	1300.00			
ZT VBS DairyP		0.00		25.00	0.00				1300.00			
ZT VBS StableP		0.00		25.00			28.00		1300.00			
ZT VBS LowerStableP		0.00		25.00				60.00	1300.00			
VBS DairyP ALLMAN		0.00			0.00	15.00			1300.00			
VBS StableP ALLMAN		0.00				15.00	28.00		1300.00			
VBS LowerStableP ALLMAN		0.00				15.00		60.00	1300.00			
MT VBS DairyP ALLMAN		0.00	15.00		0.00	15.00			1300.00			
MT VBS StableP ALLMAN		0.00	15.00			15.00	28.00		1300.00			
MT VBS LowerStableP ALLMAN		0.00	15.00			15.00		60.00	1300.00			
ZT VBS DairyP ALLMAN		0.00		25.00	0.00	15.00			1300.00			
ZT VBS StableP ALLMAN		0.00		25.00		15.00	28.00		1300.00			
ZT VBS LowerStableP ALLMAN		0.00		25.00		15.00		60.00	1300.00			
MT VBS DairyP CvrCropSlge		0.00	15.00		0.00				1300.00	30.00		
MT VBS StableP CvrCropSlge		0.00	15.00				28.00		1300.00	30.00		
MT VBS LowerStableP CvrCropSlge		0.00	15.00					60.00	1300.00	30.00		
MT VBS DairyP CvrCropSlge(SOY)		0.00	15.00		0.00				1300.00		30.00	
MT VBS StableP CvrCropSlge(SOY)		0.00	15.00				28.00		1300.00		30.00	
MT VBS LowerStableP CvrCropSlge(SOY)		0.00	15.00					60.00	1300.00		30.00	
MT DairyP CvrCropSlge		0.00	15.00		0.00					30.00		
MT StableP CvrCropSlge		0.00	15.00				28.00			30.00		
MT LowerStableP CvrCropSlge		0.00	15.00					60.00		30.00		
MT DairyP CvrCropSlge(SOY)		0.00	15.00		0.00						30.00	
MT StableP CvrCropSlge(SOY)		0.00	15.00				28.00				30.00	
MT LowerStableP CvrCropSlge(SOY)		0.00	15.00					60.00			30.00	
MT VBS DairyP CvrCropSlge ALLMAN		0.00	15.00		0.00	15.00			1300.00	30.00		
MT VBS StableP CvrCropSlge ALLMAN		0.00	15.00			15.00	28.00		1300.00	30.00		
MT VBS LowerStableP CvrCropSlge ALLMAN		0.00	15.00			15.00		60.00	1300.00	30.00		
MT VBS DairyP CvrCropSlge(SOY) ALLMAN		0.00	15.00		0.00	15.00			1300.00		30.00	
MT VBS StableP CvrCropSlge(SOY) ALLMAN		0.00	15.00			15.00	28.00		1300.00		30.00	
MT VBS LowerStableP CvrCropSlge(SOY) ALLMAN		0.00	15.00			15.00		60.00	1300.00		30.00	
MT DairyP CvrCropSlge ALLMAN		0.00	15.00		0.00	15.00				30.00		
MT StableP CvrCropSlge ALLMAN		0.00	15.00			15.00	28.00			30.00		
MT LowerStableP CvrCropSlge ALLMAN		0.00	15.00			15.00		60.00		30.00		
MT DairyP CvrCropSlge(SOY) ALLMAN		0.00	15.00		0.00	15.00					30.00	
MT StableP CvrCropSlge(SOY) ALLMAN		0.00	15.00			15.00	28.00				30.00	
MT LowerStableP CvrCropSlge(SOY) ALLMAN		0.00	15.00			15.00		60.00			30.00	
BioFuel DairyP		0.00			0.00							75.00
BioFuel StableP		0.00					28.00					75.00
BioFuel LowerStableP		0.00						60.00				75.00
MT BioFuel DairyP		0.00	15.00		0.00							75.00
MT BioFuel StableP		0.00	15.00				28.00					75.00
MT BioFuel LowerStableP		0.00	15.00					60.00				75.00
ZT BioFuel DairyP		0.00		25.00	0.00							75.00
ZT BioFuel StableP		0.00		25.00			28.00					75.00
ZT BioFuel LowerStableP		0.00		25.00				60.00				75.00
BioFuel DairyP ALLMAN		0.00			0.00	15.00						75.00
BioFuel StableP ALLMAN		0.00				15.00	28.00					75.00
BioFuel LowerStableP ALLMAN		0.00				15.00		60.00				75.00
MT BioFuel DairyP ALLMAN		0.00	15.00		0.00	15.00						75.00
MT BioFuel StableP ALLMAN		0.00	15.00			15.00	28.00					75.00
MT BioFuel LowerStableP ALLMAN		0.00	15.00			15.00		60.00				75.00
ZT BioFuel DairyP ALLMAN		0.00		25.00	0.00	15.00						75.00
ZT BioFuel StableP ALLMAN		0.00		25.00		15.00	28.00					75.00
ZT_BioFuel_LowerStableP_ALLMAN		0.00		25.00		15.00		60.00				75.00
BioFuel_VBS__DairyP		0.00			0.00				1300.00			75.00
BioFuel_VBS__StableP		0.00					28.00		1300.00			75.00
BioFuel_VBS__LowerStableP		0.00						60.00	1300.00			75.00
MT_BioFuel_VBS__DairyP		0.00	15.00		0.00				1300.00			75.00
MT_BioFuel_VBS__StableP		0.00	15.00				28.00		1300.00			75.00
MT_BioFuel_VBS__LowerStableP		0.00	15.00					60.00	1300.00			75.00
ZT_BioFuel_VBS__DairyP		0.00		25.00	0.00				1300.00			75.00
ZT_BioFuel_VBS__StableP		0.00		25.00			28.00		1300.00			75.00
ZT_BioFuel_VBS__LowerStableP		0.00		25.00				60.00	1300.00			75.00
BioFuel_VBS__DairyP_ALLMAN		0.00			0.00	15.00			1300.00			75.00
BioFuel_VBS__StableP_ALLMAN		0.00				15.00	28.00		1300.00			75.00
BioFuel_VBS__LowerStableP_ALLMAN		0.00				15.00		60.00	1300.00			75.00
MT_BioFuel_VBS__DairyP_ALLMAN		0.00	15.00		0.00	15.00			1300.00			75.00
MT_BioFuel_VBS__StableP_ALLMAN		0.00	15.00			15.00	28.00		1300.00			75.00
MT_BioFuel_VBS__LowerStableP_ALLMAN		0.00	15.00			15.00		60.00	1300.00			75.00
ZT_BioFuel_VBS__DairyP_ALLMAN		0.00		25.00	0.00	15.00			1300.00			75.00
ZT_BioFuel_VBS__StableP_ALLMAN		0.00		25.00		15.00	28.00		1300.00			75.00
ZT_BioFuel_VBS__LowerStableP_ALLMAN		0.00		25.00		15.00		60.00	1300.00			75.00
MT_BioFuel_VBS_DairyP_CvrCropSlge		0.00	15.00		0.00				1300.00	30.00		75.00
MT_BioFuel_VBS_StableP_CvrCropSlge		0.00	15.00				28.00		1300.00	30.00		75.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge		0.00	15.00					60.00	1300.00	30.00		75.00
MT_BioFuel_VBS_DairyP_CvrCropSlge(SOY)		0.00	15.00		0.00				1300.00		30.00	75.00
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)		0.00	15.00				28.00		1300.00		30.00	75.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)		0.00	15.00					60.00	1300.00		30.00	75.00
MT_BioFuel_DairyP_CvrCropSlge		0.00	15.00		0.00					30.00		75.00
MT_BioFuel_StableP_CvrCropSlge		0.00	15.00				28.00			30.00		75.00
MT_BioFuel_LowerStableP_CvrCropSlge		0.00	15.00					60.00		30.00		75.00
MT_BioFuel_DairyP_CvrCropSlge(SOY)		0.00	15.00		0.00						30.00	75.00
MT_BioFuel_StableP_CvrCropSlge(SOY)		0.00	15.00				28.00				30.00	75.00
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)		0.00	15.00					60.00			30.00	75.00
MT_BioFuel_VBS_DairyP_CvrCropSlge_ALLMAN		0.00	15.00		0.00	15.00			1300.00	30.00		75.00
MT_BioFuel_VBS_StableP_CvrCropSlge_ALLMAN		0.00	15.00			15.00	28.00		1300.00	30.00		75.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge_ALLMAN		0.00	15.00			15.00		60.00	1300.00	30.00		75.00
MT_BioFuel_VBS_DairyP_CvrCropSlge(SOY)_ALLMAN		0.00	15.00		0.00	15.00			1300.00		30.00	75.00
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)_ALLMAN		0.00	15.00			15.00	28.00		1300.00		30.00	75.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN		0.00	15.00			15.00		60.00	1300.00		30.00	75.00
MT_BioFuel_DairyP_CvrCropSlge_ALLMAN		0.00	15.00		0.00	15.00				30.00		75.00
MT_BioFuel_StableP_CvrCropSlge_ALLMAN		0.00	15.00			15.00	28.00			30.00		75.00
MT_BioFuel_LowerStableP_CvrCropSlge_ALLMAN		0.00	15.00			15.00		60.00		30.00		75.00
MT_BioFuel_DairyP_CvrCropSlge(SOY)_ALLMAN		0.00	15.00		0.00	15.00					30.00	75.00
MT_BioFuel_StableP_CvrCropSlge(SOY)_ALLMAN		0.00	15.00			15.00	28.00				30.00	75.00
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)_ALLMAN		0.00	15.00			15.00		60.00			30.00	75.00

Table E-7. BMP Thresholds (j)

BMP Regime	CT	MT	ZT	DP	MAN_INC	STABLE_P	STABLE_LOWER_P	VBS	CvrCropSlge	CvrCropSlge(SOY)	BioFuel
BASELINE											
DairyP											
Stable_P											
LowerStableP											
MT_DairyP		0.25									
MT_Stable_P		0.25									
MT_LowerStableP		0.25									
ZT_DairyP			0.25								
ZT_Stable_P			0.25								
ZT_LowerStableP			0.25								
DairyP_ALLMAN					1.00						
Stable_P_ALLMAN					1.00						
LowerStableP_ALLMAN					1.00						
MT_DairyP_ALLMAN		0.25			1.00						
MT_Stable_P_ALLMAN		0.25			1.00						
MT_Lower_Stable_P_ALLMAN		0.25			1.00						
ZT_DairyP_ALLMAN			0.25		1.00						
ZT_Stable_P_ALLMAN			0.25		1.00						
ZT_Lower_Stable_P_ALLMAN			0.25		1.00						
VBS_DairyP								1.00			
VBS_StableP								1.00			
VBS_LowerStableP								1.00			
MT_VBS_DairyP		0.25						1.00			
MT_VBS_StableP		0.25						1.00			
MT_VBS_LowerStableP		0.25						1.00			
ZT_VBS_DairyP			0.25					1.00			
ZT_VBS_StableP			0.25					1.00			
ZT_VBS_LowerStableP			0.25					1.00			
VBS_DairyP_ALLMAN					1.00			1.00			
VBS_StableP_ALLMAN					1.00			1.00			
VBS_LowerStableP_ALLMAN					1.00			1.00			
MT_VBS_DairyP_ALLMAN		0.25			1.00			1.00			
MT_VBS_StableP_ALLMAN		0.25			1.00			1.00			
MT_VBS_LowerStableP_ALLMAN		0.25			1.00			1.00			
ZT_VBS_DairyP_ALLMAN			0.25		1.00			1.00			
ZT_VBS_StableP_ALLMAN			0.25		1.00			1.00			
ZT_VBS_LowerStableP_ALLMAN			0.25		1.00			1.00			
MT_VBS_DairyP_CvrCropSlge		0.25						1.00	1.00		
MT_VBS_StableP_CvrCropSlge		0.25						1.00	1.00		
MT_VBS_LowerStableP_CvrCropSlge		0.25						1.00	1.00		
MT_VBS_DairyP_CvrCropSlge(SOY)		0.25						1.00		1.00	
MT_VBS_StableP_CvrCropSlge(SOY)		0.25						1.00		1.00	
MT_VBS_LowerStableP_CvrCropSlge(SOY)		0.25						1.00		1.00	
MT_DairyP_CvrCropSlge		0.25							1.00		
MT_StableP_CvrCropSlge		0.25							1.00		
MT_LowerStableP_CvrCropSlge		0.25							1.00		
MT_DairyP_CvrCropSlge(SOY)		0.25								1.00	
MT_StableP_CvrCropSlge(SOY)		0.25								1.00	
MT_LowerStableP_CvrCropSlge(SOY)		0.25								1.00	
MT_VBS_DairyP_CvrCropSlge_ALLMAN		0.25			1.00			1.00	1.00		
MT_VBS_StableP_CvrCropSlge_ALLMAN		0.25			1.00			1.00	1.00		
MT_VBS_LowerStableP_CvrCropSlge_ALLMAN		0.25			1.00			1.00	1.00		
MT_VBS_DairyP_CvrCropSlge(SOY)_ALLMAN		0.25			1.00			1.00		1.00	
MT_VBS_StableP_CvrCropSlge(SOY)_ALLMAN		0.25			1.00			1.00		1.00	
MT_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN		0.25			1.00			1.00		1.00	
MT_DairyP_CvrCropSlge_ALLMAN		0.25			1.00				1.00		
MT_StableP_CvrCropSlge_ALLMAN		0.25			1.00				1.00		
MT_LowerStableP_CvrCropSlge_ALLMAN		0.25			1.00				1.00		
MT_DairyP_CvrCropSlge(SOY)_ALLMAN		0.25			1.00					1.00	
MT_StableP_CvrCropSlge(SOY)_ALLMAN		0.25			1.00					1.00	
MT_LowerStableP_CvrCropSlge(SOY)_ALLMAN		0.25			1.00					1.00	
BioFuel_DairyP											1.00
BioFuel_StableP											1.00
BioFuel_LowerStableP											1.00
MT_BioFuel_DairyP		0.25									1.00
MT_BioFuel_StableP		0.25									1.00
MT_BioFuel_LowerStableP		0.25									1.00
ZT_BioFuel_DairyP			0.25								1.00
ZT_BioFuel_StableP			0.25								1.00
ZT_BioFuel_LowerStableP			0.25								1.00
BioFuel_DairyP_ALLMAN					1.00						1.00
BioFuel_StableP_ALLMAN					1.00						1.00
BioFuel_LowerStableP_ALLMAN					1.00						1.00
MT_BioFuel_DairyP_ALLMAN		0.25			1.00						1.00
MT_BioFuel_StableP_ALLMAN		0.25			1.00						1.00
MT_BioFuel_LowerStableP_ALLMAN		0.25			1.00						1.00
ZT_BioFuel_DairyP_ALLMAN			0.25		1.00						1.00
ZT_BioFuel_StableP_ALLMAN			0.25		1.00						1.00
ZT_BioFuel_LowerStableP_ALLMAN			0.25		1.00						1.00
BioFuel_VBS__DairyP								1.00			1.00
BioFuel_VBS__StableP								1.00			1.00
BioFuel_VBS__LowerStableP								1.00			1.00
MT_BioFuel_VBS__DairyP		0.25						1.00			1.00
MT_BioFuel_VBS__StableP		0.25						1.00			1.00
MT_BioFuel_VBS__LowerStableP		0.25						1.00			1.00
ZT_BioFuel_VBS__DairyP			0.25					1.00			1.00
ZT_BioFuel_VBS__StableP			0.25					1.00			1.00
ZT_BioFuel_VBS__LowerStableP			0.25					1.00			1.00
BioFuel_VBS__DairyP_ALLMAN					1.00			1.00			1.00
BioFuel_VBS__StableP_ALLMAN					1.00			1.00			1.00
BioFuel_VBS__LowerStableP_ALLMAN					1.00			1.00			1.00
MT_BioFuel_VBS__DairyP_ALLMAN		0.25			1.00			1.00			1.00
MT_BioFuel_VBS__StableP_ALLMAN		0.25			1.00			1.00			1.00
MT_BioFuel_VBS__LowerStableP_ALLMAN		0.25			1.00			1.00			1.00
ZT_BioFuel_VBS__DairyP_ALLMAN			0.25		1.00			1.00			1.00
ZT_BioFuel_VBS__StableP_ALLMAN			0.25		1.00			1.00			1.00
ZT_BioFuel_VBS__LowerStableP_ALLMAN			0.25		1.00			1.00			1.00
MT_BioFuel_VBS_DairyP_CvrCropSlge		0.25						1.00	1.00		1.00
MT_BioFuel_VBS_StableP_CvrCropSlge		0.25						1.00	1.00		1.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge		0.25						1.00	1.00		1.00
MT_BioFuel_VBS_DairyP_CvrCropSlge(SOY)		0.25						1.00		1.00	1.00
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)		0.25						1.00		1.00	1.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)		0.25						1.00		1.00	1.00
MT_BioFuel_DairyP_CvrCropSlge		0.25							1.00		1.00
MT_BioFuel_StableP_CvrCropSlge		0.25							1.00		1.00
MT_BioFuel_LowerStableP_CvrCropSlge		0.25							1.00		1.00
MT_BioFuel_DairyP_CvrCropSlge(SOY)		0.25								1.00	1.00
MT_BioFuel_StableP_CvrCropSlge(SOY)		0.25								1.00	1.00
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)		0.25								1.00	1.00
MT_BioFuel_VBS_DairyP_CvrCropSlge_ALLMAN		0.25			1.00			1.00	1.00		1.00
MT_BioFuel_VBS_StableP_CvrCropSlge_ALLMAN		0.25			1.00			1.00	1.00		1.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge_ALLMAN		0.25			1.00			1.00	1.00		1.00
MT_BioFuel_VBS_DairyP_CvrCropSlge(SOY)_ALLMAN		0.25			1.00			1.00		1.00	1.00
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)_ALLMAN		0.25			1.00			1.00		1.00	1.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN		0.25			1.00			1.00		1.00	1.00
MT_BioFuel_DairyP_CvrCropSlge_ALLMAN		0.25			1.00				1.00		1.00
MT_BioFuel_StableP_CvrCropSlge_ALLMAN		0.25			1.00				1.00		1.00
MT_BioFuel_LowerStableP_CvrCropSlge_ALLMAN		0.25			1.00				1.00		1.00

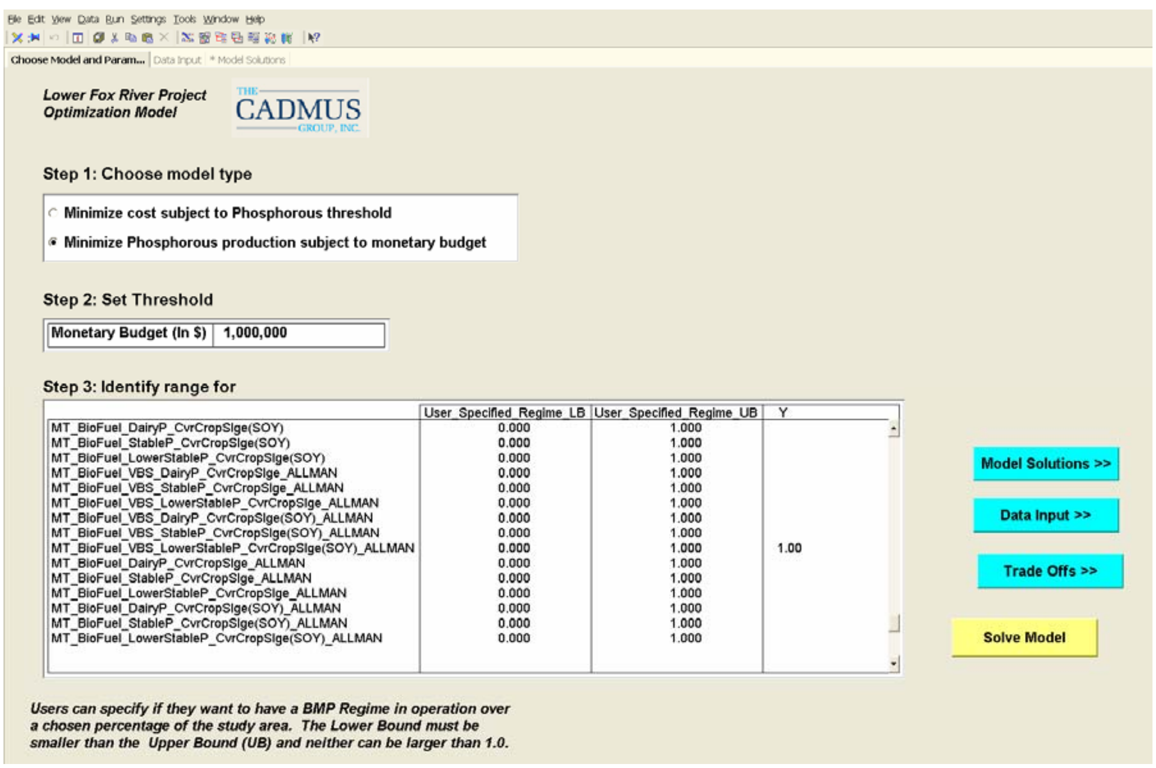
On the first screen of OptiMod (Figure E-1**Error! Not a valid bookmark self-reference.**), the user is prompted to choose the type of optimization model to run: (1) minimize cost given a maximum allowable phosphorus load, or (2) minimize the phosphorus load given a budget. "Minimize phosphorus load given a budget" was selected for the demonstration analysis (see box in Step 1 of Figure E-1**Error! Not a valid bookmark self-reference.**).

The box in Step 2, "Monetary Budget in ($)," allows the user to input a maximum total cost for the solution. $1,000,000 was selected so as not to constrain the solution.

The box in Step 3, "Identify range for," allows the user to set an upper and lower bound for each BMP scenario being evaluated in the model. For this analysis, the defaults (0 lower, 1 upper) were selected – at these levels, these constraints will not affect the solution.

The last column of the box in Step 3 shows the current optimal solution to the model (identified by the 1 in the Y column in Figure E-1). This optimal BMP scenario that produces the minimum phosphorus load is "MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN" – 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.

Figure E-1. Choose Model Page



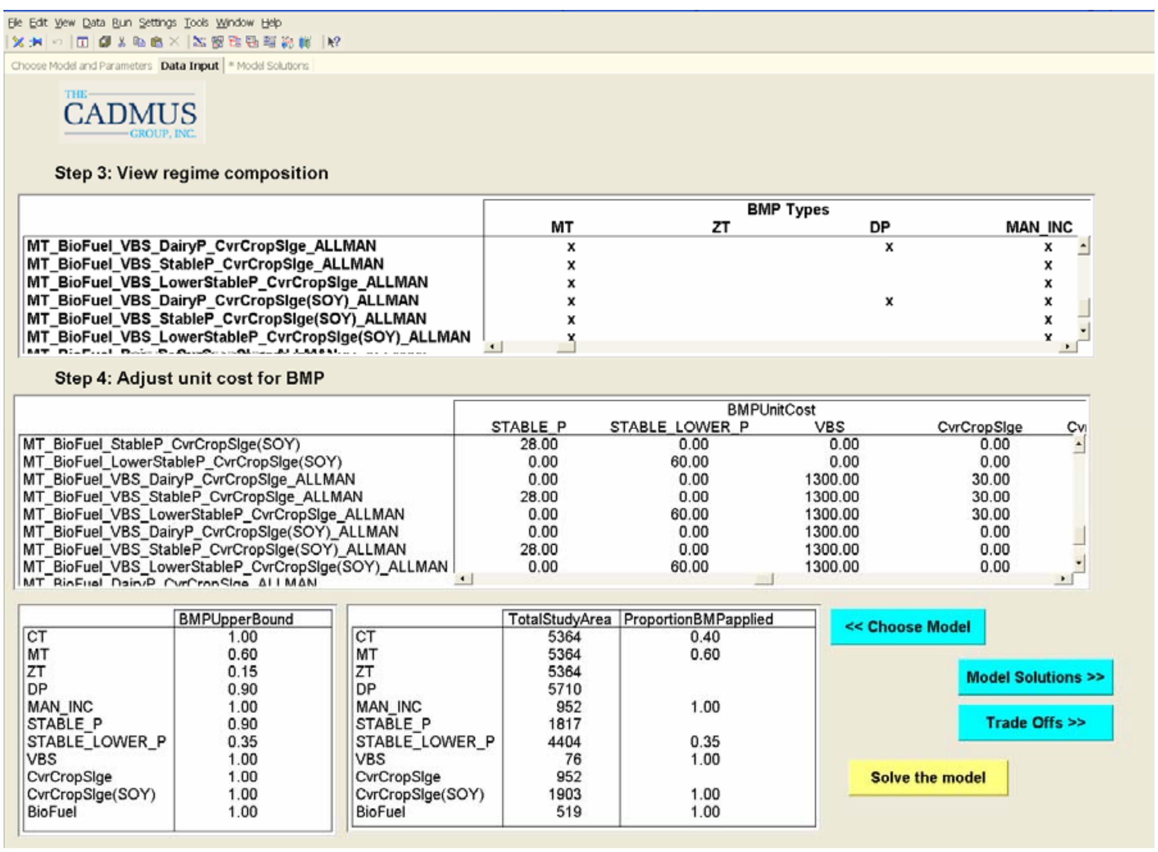
The Data Input Page (Figure E-2) contains the input data for the model. The Step 3 box, "View regime composition" allows the user to view (and change if necessary) the composition of the BMP scenarios. An "X" indicates that the BMP in the column heading is a part of the BMP scenario shown in the row.

In Step 4, "Adjust unit cost for BMP," the user can change any of the unit costs for any BMP in any BMP scenario. The leftmost table at the bottom of the Data Input Page shows the current BMP Upper Bound values (the maximum proportion of the available area for the BMP; the default is 1). For the demonstration analysis, the maximum application amounts were chosen (60% for MT, 15% for ZT, 90% for DP and STABLE_P, and 35% for STABLE_LOWER_P) and used in all model solutions.

The table to the right shows the size of the study area to which each of the BMPs can be applied (TotalStudyArea(j)); for example zone tillage can be applied to a maximum of 5,364 acres in the test study area, while vegetative buffer strips can be applied to a maximum of 76 acres. Users can change the values in either table.

The second column of the lower right table shows the proportions of each of the BMPs chosen in this optimal solution, for example, MT is applied to 60% of the allowable acreage.

Figure E-2. Data Input Page

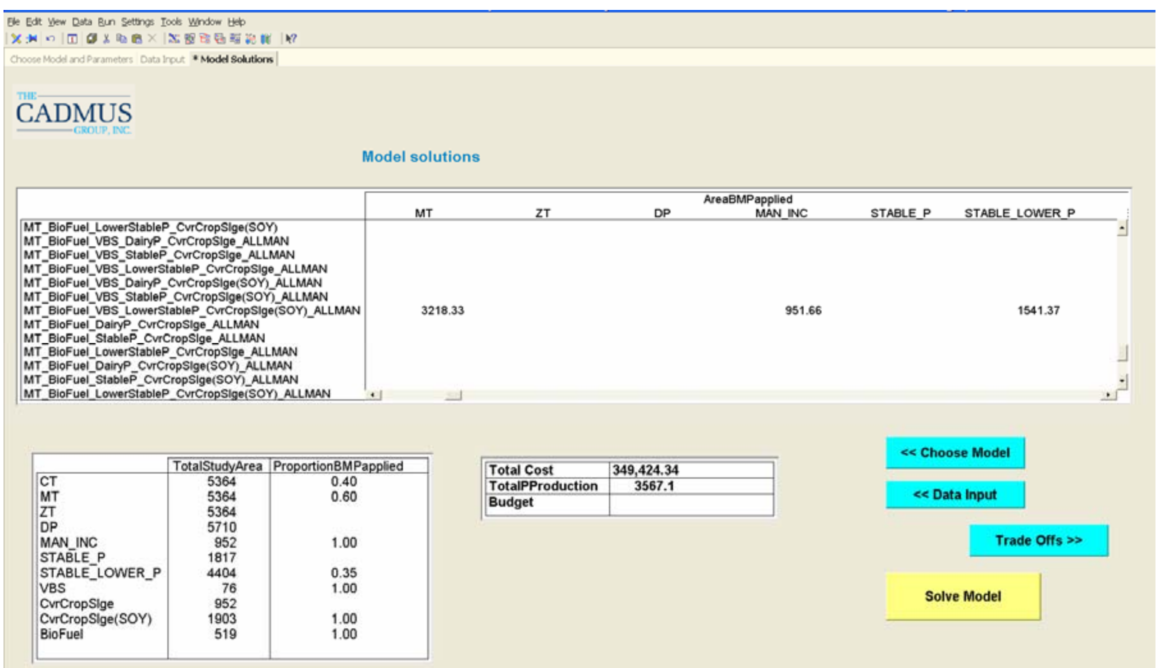


The "Model Solutions" page (Figure E-3) shows the area to which each of the BMPs is applied in the optimal solution. The optimal BMP scenario is "MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN," with mulch tillage applied to 3,218 acres (conventional tillage to the remaining 2,146 acres), manure incorporation on the allowable 952 acres, soil phosphorus reduced to 25 ppm on 1,541 acres, planting switchgrass as a bio-fuel crop on 519 acres, 76 acres of vegetative buffer strips, and 1,903 acres for planting cover crops on corn silage and soybean crop fields.

The Total Study Area table (at the bottom left of Figure E-3**Error! Reference source not found.**) is repeated on this page for ease of comparison of the optimal amounts for each BMP to the maximum allowable application area (i.e., mulch tillage is applied to 60% of the available area, while cover crop on soybean fields is applied to 100% of the available area).

As shown in Figure E-3, the total cost of implementing this optimal BMP scenario solution is slightly less than $350,000, and reduces total phosphorus loading from the *2004 Baseline* load of 5,688 kg to 3,567 kg (a reduction of 2,121 kg or 37%).

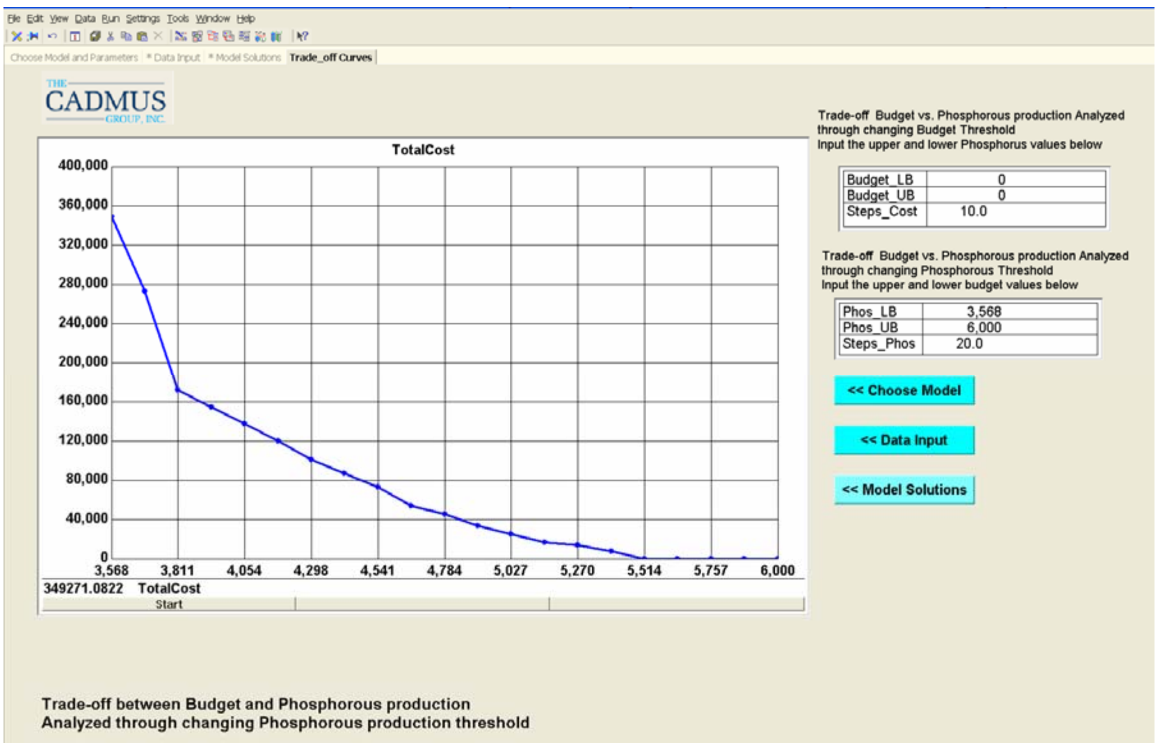
Figure E-3. Model Solutions Page



The "Trade-Offs" page (Figures F-4 and F-5) allows the user to see how BMP implementation costs behave when changing the phosphorus loading threshold. Users can input an upper and lower bound for the threshold, here 3,568 kg (3,567.1 kg was found to be the minimum given the input data and constraints) as a lower bound, and 6,000 kg for the upper bound. The graph in Figure E-4**Error! Reference source not found.** shows this trade-off within the input range.

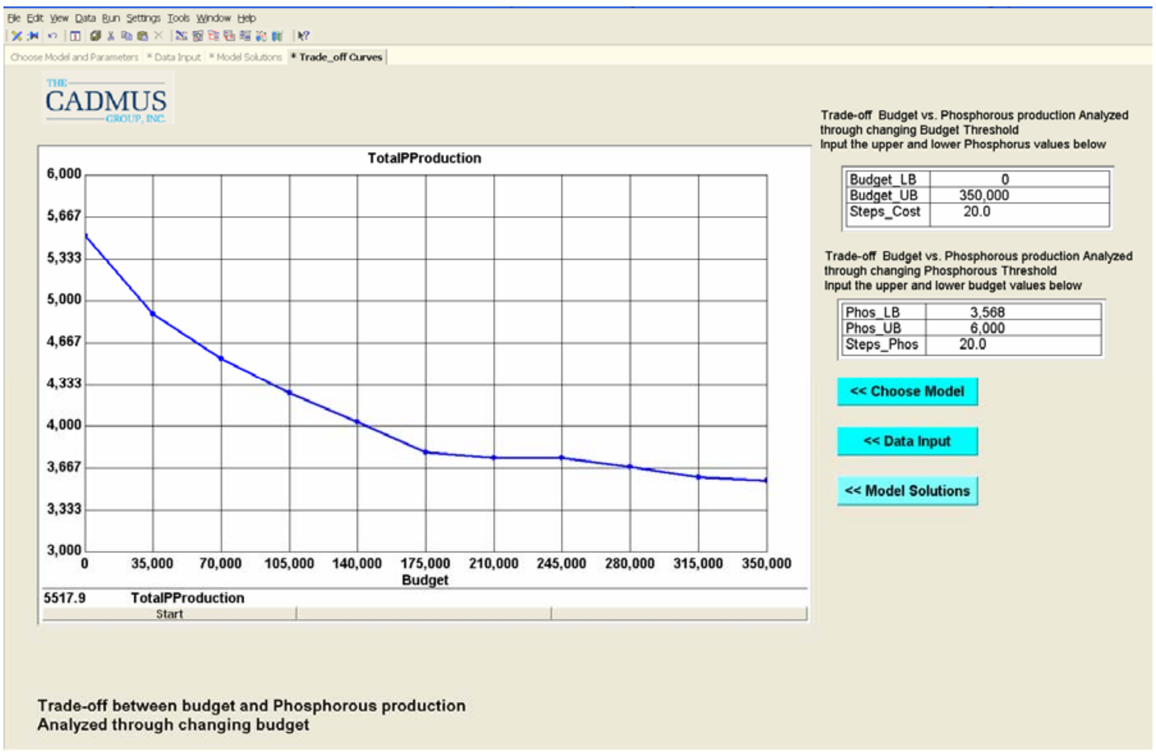
To reduce total phosphorus loading from 6,000 kg to approximately 5,514 kg, BMP implementation costs are $0 because there is no cost for implementing the DairyP BMP. However, as phosphorus is reduced from about 5,514 kg to approximately 3,811 kg, costs begin to rise (exponentially) to approximately $170,000. Costs then rise steeply (to a maximum of $350,000) to achieve the maximum phosphorus reductions.

Figure E-4. Trade-off Analysis Page (varying phosphorus load reductions)



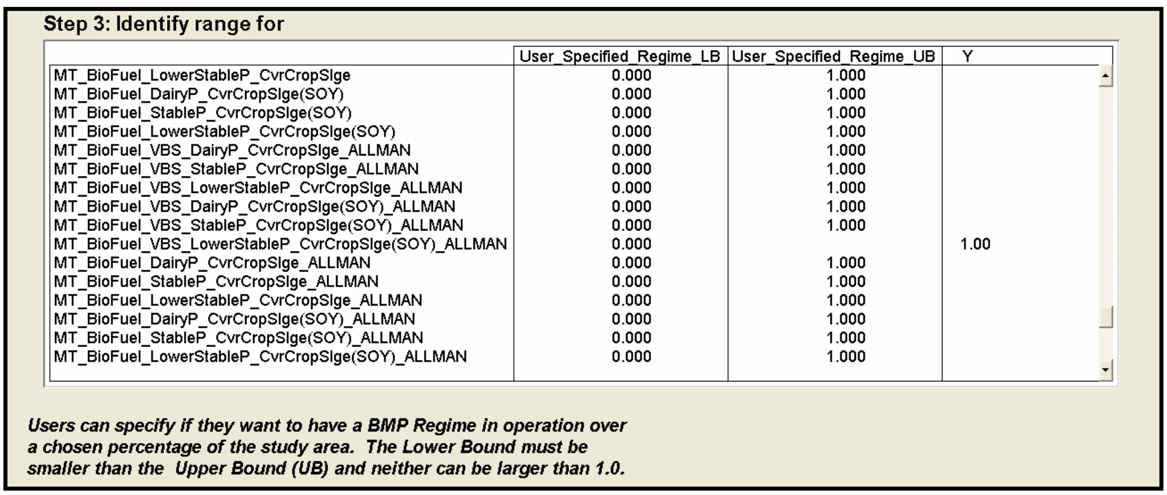
OptiMod also allows users to develop a trade-off curve when varying the budget (Figure E-5**Error! Reference source not found.**). This provides the same information in Figure E-4**Error! Reference source not found.**, but in a different format. While the budget is decreased from $350,000 to $175,000, the increase in total phosphorus loading is relatively small from 3,567 kg to 3,793 kg. Decreasing the budget after that rapidly increases phosphorus loading.

Figure E-5. Trade-off Analysis Page (varying the budget)



As already mentioned, OptiMod was run using the Minimize Phosphorus Load (Z2) mode with a large enough budget to not constrain the solution. The resulting optimal BMP scenario solution ("MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN") achieves a reduced total phosphorus loading of 3,567 kg (about 37%), at a cost of slightly less than $350,000. In addition to identifying the optimal solution, OptiMod was also used to identify the nine next best BMP scenarios that can reduce total phosphorus loading by as close to 50% as possible. To obtain the next best solutions, the model was used to successively set the BMP Scenario Upper Bound to 0 for those BMP scenarios chosen previously in OptiMod. For example the Upper Bound for "MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN" was set to 0 (Figure E-6), and OptiMod was run again, resulting in "MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)_ALLMAN" as the optimal solution (Figure E-7).

Figure E-6. Setting Upper Bound for "MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN" to 0

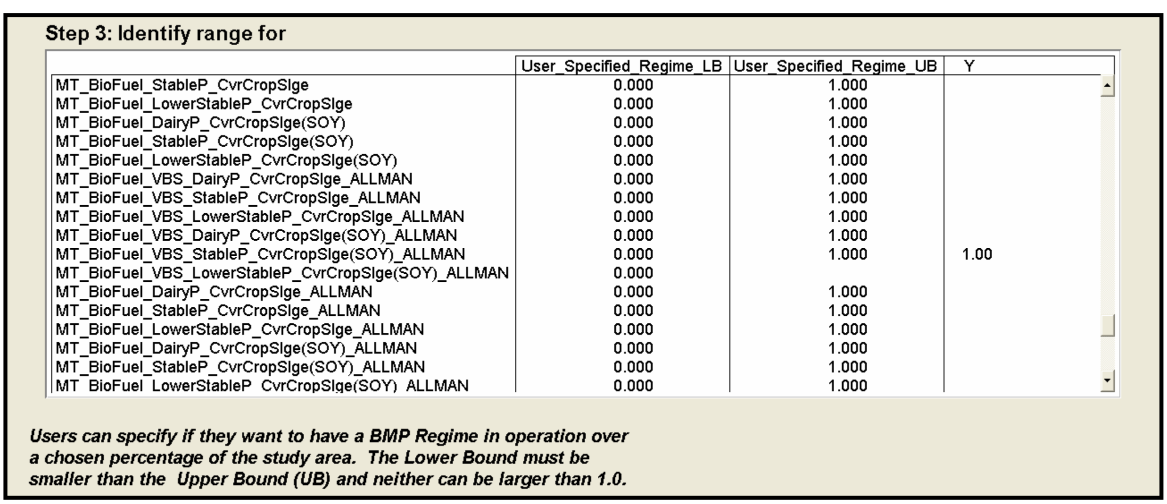


Step 3: Identify range for

	User_Specified_Regime_LB	User_Specified_Regime_UB	Y
MT_BioFuel_LowerStableP_CvrCropSlge	0.000	1.000	
MT_BioFuel_DairyP_CvrCropSlge(SOY)	0.000	1.000	
MT_BioFuel_StableP_CvrCropSlge(SOY)	0.000	1.000	
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)	0.000	1.000	
MT_BioFuel_VBS_DairyP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_VBS_StableP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_VBS_LowerStableP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_VBS_DairyP_CvrCropSlge(SOY)_ALLMAN	0.000	1.000	
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)_ALLMAN	0.000	1.000	
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN	0.000		1.00
MT_BioFuel_DairyP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_StableP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_LowerStableP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_DairyP_CvrCropSlge(SOY)_ALLMAN	0.000	1.000	
MT_BioFuel_StableP_CvrCropSlge(SOY)_ALLMAN	0.000	1.000	
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)_ALLMAN	0.000	1.000	

Users can specify if they want to have a BMP Regime in operation over a chosen percentage of the study area. The Lower Bound must be smaller than the Upper Bound (UB) and neither can be larger than 1.0.

Figure E-7. Optimal Solution with "MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN" set to 0



Step 3: Identify range for

	User_Specified_Regime_LB	User_Specified_Regime_UB	Y
MT_BioFuel_StableP_CvrCropSlge	0.000	1.000	
MT_BioFuel_LowerStableP_CvrCropSlge	0.000	1.000	
MT_BioFuel_DairyP_CvrCropSlge(SOY)	0.000	1.000	
MT_BioFuel_StableP_CvrCropSlge(SOY)	0.000	1.000	
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)	0.000	1.000	
MT_BioFuel_VBS_DairyP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_VBS_StableP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_VBS_LowerStableP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_VBS_DairyP_CvrCropSlge(SOY)_ALLMAN	0.000	1.000	
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)_ALLMAN	0.000	1.000	1.00
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN	0.000		
MT_BioFuel_DairyP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_StableP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_LowerStableP_CvrCropSlge_ALLMAN	0.000	1.000	
MT_BioFuel_DairyP_CvrCropSlge(SOY)_ALLMAN	0.000	1.000	
MT_BioFuel_StableP_CvrCropSlge(SOY)_ALLMAN	0.000	1.000	
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)_ALLMAN	0.000	1.000	

Users can specify if they want to have a BMP Regime in operation over a chosen percentage of the study area. The Lower Bound must be smaller than the Upper Bound (UB) and neither can be larger than 1.0.