Technical Report No. 60

Lake Champlain Basin Program

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

Second Year Report

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

for
Lake Champlain Basin Program and
Vermont Agency of Natural Resources

May 2010

PUBLICATION SERIES

THIS PROGRAM IS SPONSORED BY THE US EPA AND THE STATES OF NEW YORK AND VERMONT.

This technical report is the sixtieth in a series of reports prepared under the Lake Champlain Basin Program. Those in print are listed below.

Lake Champlain Basin Program Technical Reports

1. *A Research and Monitoring Agenda for Lake Champlain.* Proceedings of a Workshop, December 17-19, 1991, Burlington, VT. Lake Champlain Research Consortium. May, 1992.

2. *Design and Initial Implementation of a Comprehensive Agricultural Monitoring and Evaluation Network for the Lake Champlain Basin.* NY-VT Strategic Core Group. February, 1993.

3. (A) *GIS Management Plan for the Lake Champlain Basin Program.* Vermont Center for Geographic Information, Inc., and Associates in Rural Development. March, 1993.

   (B) *Handbook of GIS Standards and Procedures for the Lake Champlain Basin Program.* Vermont Center for Geographic Information, Inc. March, 1993.

   (C) *GIS Data Inventory for the Lake Champlain Basin Program.* Vermont Center for Geographic Information, Inc. March, 1993.

4. (A) *Lake Champlain Economic Database Project. Executive Summary.* Holmes & Associates. March 1993.

   (B) *Socio-Economic Profile, Database, and Description of the Tourism Economy for the Lake Champlain Basin.* Holmes & Associates. March 1993

   B) *Socio-Economic Profile, Database, and Description of the Tourism Economy for the Lake Champlain Basin. Appendices.* Holmes & Associates. March 1993

   (C) *Potential Applications of Economic Instruments for Environmental Protection in the Lake Champlain Basin.* Anthony Artuso. March 1993.

   (D) *Conceptual Framework for Evaluation of Pollution Control Strategies and Water Quality Standards for Lake Champlain.* Anthony Artuso. March 1993.

5. *Lake Champlain Sediment Toxics Assessment Program. An Assessment of Sediment - Associated Contaminants in Lake Champlain - Phase 1*. Alan McIntosh, Editor, UVM School of Natural Resources. February 1994.

   Lake Champlain Sediment Toxics Assessment Program. An Assessment of Sediment - Associated Contaminants in Lake Champlain - Phase 1. Executive Summary. Alan McIntosh, Editor, UVM School of Natural Resources. February 1994.

6. *(A) Lake Champlain Nonpoint Source Pollution Assessment.* Lenore Budd, Associates in Rural Development Inc. and Donald Meals, UVM School of Natural Resources. February 1994.

   (B) Lake Champlain Nonpoint Source Pollution Assessment. Appendices A-J. Lenore Budd, Associates in Rural Development Inc. and Donald Meals, UVM School of Natural Resources. February 1994.

7. *Internal Phosphorus Loading Studies of St. Albans Bay. Executive Summary.* VT Dept of Environmental Conservation. March 1994.

(A) *Dynamic Mass Balance Model of Internal Phosphorus Loading in St. Albans Bay, Lake Champlain.* Eric Smeltzer, Neil Kamman, Karen Hyde and John C. Drake. March 1994.

(B) *History of Phosphorus Loading to St. Albans Bay, 1850 - 1990.* Karen Hyde, Neil Kamman and Eric Smeltzer. March 1994.

(C) *Assessment of Sediment Phosphorus Distribution and Long-Term Recycling in St. Albans Bay, Lake Champlain.* Scott Martin, Youngstown State University. March 1994.

8. *Lake Champlain Wetlands Acquisition Study.* Jon Binhammer, VT Nature Conservancy. June 1994.

9. *A Study of the Feasibility of Restoring Lake Sturgeon to Lake Champlain.* Deborah A. Moreau and Donna L. Parrish, VT Cooperative Fish & Wildlife Research Unit, University of Vermont. June 1994.

10. *Population Biology and Management of Lake Champlain Walleye.* Kathleen L. Newbrough, Donna L. Parrish, and Matthew G. Mitro, Fish & Wildlife Research Unit, University of Vermont. June 1994.

11. (A) *Report on Institutional Arrangements for Watershed Management of the Lake Champlain Basin. Executive Summary.* Yellow Wood Associates, Inc. January 1995.

(B) *Report on Institutional Arrangements for Watershed Management of the Lake Champlain Basin.* Yellow Wood Associates, Inc. January 1995.

(C) *Report on Institutional Arrangements for Watershed Management of the Lake Champlain Basin. Appendices.* Yellow Wood Associates, Inc. January 1995.

12. (A) *Preliminary Economic Analysis of the Draft Plan for the Lake Champlain Basin Program. Executive Summary.* Holmes & Associates and Anthony Artuso. March 1995

(B) *Preliminary Economic Analysis of the Draft Plan for the Lake Champlain Basin Program.* Holmes & Associates and Anthony Artuso. March 1995

13. *Patterns of Harvest and Consumption of Lake Champlain Fish and Angler Awareness of Health Advisories.* Nancy A. Connelly and Barbara A. Knuth. September 1995.

14. (A) *Preliminary Economic Analysis of the Draft Plan for the Lake Champlain Basin Program. Executive Summary - Part 2.* Holmes & Associates and Anthony Artuso. November 1995

(B) *Preliminary Economic Analysis of the Draft Plan for the Lake Champlain Basin Program - Part 2.* Holmes & Associates and Anthony Artuso. November 1995

15. *Zebra Mussels and Their Impact on Historic Shipwrecks.* Lake Champlain Maritime Museum. January 1996.

16. *Background Technical Information for Opportunities for Action: An Evolving Plan for the Future of the Lake Champlain Basin.* Lake Champlain Basin Program. June 1996

17. (A) *Executive Summary. Economic Analysis of the Draft Final Plan for the Lake Champlain Management Conference.* Holmes & Associates and Anthony Artuso. July 1996

    (B) *Economic Analysis of the Draft Final Plan for the Lake Champlain Basin Management Conference.* Holmes & Associates and Anthony Artuso. July 1996

18. *Catalog of Digital Spatial Data for the Lake Champlain Basin* . Vermont Center for Geographic Information, Inc. September 1996.

19. *Hydrodynamic and Water Quality Modeling of Lake Champlain.* Applied Science Associates, Inc. July 1996.

20. *Understanding Phosphorus Cycling, Transport and Storage in Stream Ecosystems as a Basis for Phosphorus Management. Dr. James P.* Hoffmann, Dr. E. Alan Cassell, Dr. John C. Drake, Dr. Suzanne Levine, Mr. Donald W. Meals, Jr., Dr. Deane Wang. December 1996.

21. *Bioenergetics Modeling for Lake Trout and other Top Predators in Lake Champlain.* Dr. George W. LaBar and Dr. Donna L. Parrish. December 1996

22. *Characterization of On-Farm Phosphorus Budgets and Management in the Lake Champlain Basin.* Robert D. Allshouse, Everett D. Thomas, Charles J. Sniffen, Kristina Grimes, Carl Majewski - Miner Agricultural Research Institute. April 1997

23. (A) *Lake Champlain Sediment Toxics Assessment Program. An Assessment of Sediment - Associated Contaminants in Lake Champlain - Phase 11*. *Executive Summary*. Alan McIntosh, Mary Watzin and Erik Brown, UVM School of Natural Resources. October 1997

    (B) Lake Champlain Sediment Toxics Assessment Program. An Assessment of Sediment - Associated Contaminants in Lake Champlain - Phase 11. Alan McIntosh, Mary Watzin and Erik Brown, UVM School of Natural Resources. October 1997

24. *Development of Land Cover/Land Use Geographic Information System Data Layer for the Lake Champlain Basin and Vermont Northern Forest Lands Project Areas.* Dr. Thomas Millette. October 1997

25. *Urban Nonpoint Pollution Source Assessment of the Greater Burlington Area.* Urban Stormwater Characterization Project. James Pease, VT Dept. of Environmental Conservation. December 1997

26. *Long-Term Water Quality and Biological Monitoring project for Lake Champlain.* Cumulative Report for Project Years 1992- 1996. VT Dept of Environmental Conservation and NYS Dept of Environmental Conservation. March 1998.

27. *Cumberland Bay PCB Study.* Clifford W Callinan, NY State Dept. of Environmental Conservation; Lyn McIlroy, Ph.D., SUNY Plattsburgh; and Robert D. Fuller, PhD., SUNY Plattsburgh. October 1998.

28. *Lake Champlain Underwater Cultural Resources Survey. Volume 1: Lake Survey Background and 1996 Results.* Scott A. McLaughlin and Anne W. Lessman, under the direction of Arthur B. Cohn, Lake Champlain Maritime Museum. December 1998.

29. *Evaluation of Soil Factors Controlling Phosphorus Concentration in Runoff from Agricultural Soils in the Lake Champlain Basin.* Frederick R. Magdoff, William E. Jokela, and Robert P. Durieux, UVM Department of Plant and Soil Sciences. June 1997.

30. *Lower Trophic Level Interactions in the Pelagic Foodweb of Lake Champlain.* Dr. Suzanne N. Levine, Dr. Mark Borchardt, Dr. Moshe Braner, Angela Shambaugh, and Susan Spencer of UVM School of Natural Resources and Marshfield Medical Research Foundation. July 1997.

31. Estimation of Lake Champlain Basinwide Nonpoint Source Phosphorus Export, William Hegman, Associates in Rural Development, Inc., Deane Wang and Catherine Borer, UVM Water Resources & Lake Study Center, September 1999.

32. *The Freshwater Mussels of the Lower Missisquoi Rivers: Current Status and the Potential for a Refugium from Zebra Mussel Impacts.* Paul Marangelo, VT Agency of Natural Resources, Dept of Environmental Conservation. August 1999.

33. *Ecological Effects of Sediment-Associated Contaminants in Inner Burlington Harbor, Lake Champlain.* Tetra Tech, Inc. September 1999.

34. (A) Benthic Phosphorus Cycling in Lake Champlain: Results of an Integrated Field Sampling/Water Quality Modeling Study. Part A: Water Quality Modeling. Jeffrey C. Cornwell and Michael Owens, University of Maryland Center for Environmental Sciences Horn Point Laboratory for HydroQual, Inc. June 1999.

(B) *Benthic Phosphorus Cycling in Lake Champlain: Results of an Integrated Field Sampling/Water Quality Modeling Study. Part B: Field Studie.* Jeffrey C. Cornwell and Michael Owens, University of Maryland Center for Environmental Sciences, Horn Point Laboratory for HydroQual, Inc. June 1999.

35. *Determination and Quantification of Factors Controlling Pollutant Delivery from Agricultural Land to Streams in the Lake Champlain Basin.* J.W. Hughes, W.E. Jokela, D. Wang, C. Borer, UVM. September 1999.

36. *Cost-Effective Phosphorus Removal from Secondary Wastewater Effluent through Mineral Adsorption.* Larry D. Goehring, Sr., Tammo S. Steenhuis, Andrea S. Brooks, Melissa N. Rosenwald,Jennifer Chen, Cornell University and Victor J. Putnam, Essex County Planning Department. December 1999.

37. *(A) Sea Lamprey Control Alternatives in the Lake Champlain Tributaries: Poultney, Hubbardton and Pike Rivers and Morpion Stream.* Leigh R. Walrath, Environmental Analyst and Katherine M. Swiney, Environmental Analyst, New England Interstate Water Pollution Control Commission. August 2001.

37 *(B) Assessment of Sea Lamprey Habitat and the Sea Lamprey Population of the Pike River and Morpion Stream, Quebec, Canada.* Micah Dean and Adam Zerrenner, Lake Champlain Fish and Wildlife Resources Office, United States Fish and Wildlife Service. September 2001

38. *(A) Thermal Variability in the South Lake of Lake Champlain from 1997-1999*. Tom Manley, Marine Research Corporation, September 2001.

39. *Evaluation of Potential Blue-Green Algal Toxins in Lake Champlain (Summer 2000).* Rosen, B., USDA-NRCS Wastershed Science Institute; A. Shambaugh, L. Ferber, F. Smith and M. Watzin,UVM School of Natural Resources; and C. Eliopoulos and P. Stangel, VT Department of Environmental Conservation. November 2001.

40. *Monitoring and Evaluation of Cyanobacteria in Burlington Bay, Lake Champlain (Summer 2001).* Watzin, M., A. Shambaugh, and E. Brines; UVM School of Natural Resources. November 2002.

41. *Monitoring and Evaluation of Cyanobacteria in Burlington Bay, Lake Champlain (Summer 2002).* Watzin, M., A. Shambaugh, and E.Brines; UVM,Rubenstein School of Natural Resources, December 2003.

42. *The Feeding of Supplemental Phosphorus on Dairy Farms in the Lake Champlain Basin: An Education/Demonstration Project.* Cotanch,K., C. Ballard, W. Emerich, C. Sniffen, and E. Thomas, W.H. Miner Institute. April 2003.

43. *Stage-Based Population Viability Model for Sea Lamprey (Petromyzon marinus).* Howe, Eric A., E. Marsden and T. M. Donovan, UVM School of Natural Resources and R.H. Lamberson, Humboldt University Department of Mathematics. March 2004.

44. *Exploratory Study of Dismantling Sea Lamprey Nests to Reduce Egg and Larval Production in Two Lake Champlain Basin Tributaries.* Laroche, W., Stonefish Environmental; C.D. Martin, U.S. Fish and Wildlife Service; H.P. Wimmer, Middlebury College. August 2004.

45. *Hydrologic Modeling and Conceptual Siting Analysis for the Evaluation of a Barrier to Control the Sea Lamprey Population of the Pike River and Morpion Stream, Quebec, Canada*. Young, B., U.S. Fish and Wildlife Service; C.J. Orvis, U.S. Fish and Wildlife Service. September, 2004.

46. *Ecosystem Indicators and an Environmental Score Card for the Lake Champlain Basin Program*. Watzin, M.C., R.L. Smyth, E.A. Cassell, W.C. Hession, R.E. Manning, and D. Wang, Rubenstein School of Environment and Natural Resources, University of Vermont. May 2005.

47. *Developing and Assessing Policy Options for Reducing Phosphorus Loading in Lake Champlain*. Winsten, J.R.,Henry A.Wallace Center for Agricultural and Environmental Policy at Winrock Environmental. April 2004.

48. *Tributary Contributions to the Parasitic and Spawning Adult Population of Sea Lamprey (Petromyzon marinus) in Lake Champlain Using Elemental Signatures.* Howe, E.A., C.P Hand, J.E. Marsden, S.A. Ludsin,and B.J Fryer, Rubenstein School of Environment and Natural Resources, University of Vermont; Great Lakes Institute for Environmental Research, University of Windsor; National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory. March 2006.

49. *Distribution and Factors Affecting Survival of Sea Lamprey Eggs In and Out of Nests.* Smith S., J.E.Marsden, Rubenstein School of Environment and Natural Resources, University of Vermont. April 2006.

50. *Demonstration of Methods to Reduce Indicator Bacteria Levels in Agricultural Runoff in Vermont.* Prepared by Donald W. Meals, Ice.Nine Environmental Consulting and David C. Braun, Stone Environmental, Inc. March 2005

51. Monitoring and Evaluation of Cyanobacteria in Lake Champlain Summer 2003. Mary C. Watzin, Angela D. Shambaugh, Emily K. Brines, Todd Clason, and Meghan Kreider, Rubenstein Ecosystem Science Laboratory, Rubenstein School of Environment and Natural Resources University of Vermont with support from: Gregory L. Boyer, Department of Chemistry, State University of New York, College of Environmental Science and Forestry. December 2004.

52. Monitoring and Evaluation of Cyanobacteria in Lake Champlain Summer 2004. Mary C. Watzin, Emily Brines Miller, Meghan Kreider, Sam Couture, Todd Clason, and Michael Levine, RubensteinEcosystem Science Laboratory, Rubenstein School of Environment and Natural Resources University of Vermont with support from: Gregory L. Boyer, Department of Chemistry, State University of New York, College of Environmental Science and Forestry. June 2005.

53. Monitoring and Evaluation of Cyanobacteria in Lake Champlain Summer 2005. Mary C. Watzin, Susan Fuller, Meghan Kreider, Sam Couture, and Michael Levine, Rubenstein Ecosystem Science Laboratory,Rubenstein School of Environment and Natural Resources University of Vermont with support from: Gregory L. Boyer, Department of Chemistry, State University of New York, College of Environmental Science and Forestry. June 2006.

54. Updating the Lake Champlain Basin Land Use Data to Improve Prediction of Phosphorus Loading. Austin Troy, Deane Wang, David Capen, Rubenstein School of Environment and Natural Resources University of Vermont with Project Staff: Jarlath O'Neil-Dunne and Sean MacFaden, Spatial Analysis Lab, Rubenstein School of Environment and Natural Resources University of Vermont. May 2007

55. Monitoring and Evaluation of Cyanobacteria in Lake Champlain Summer 2006. Mary C. Watzin, Susan Fuller, Meghan Rogalus, Michael Levine,Sam Couture, Kate Crawford, and Cynthia May Rubenstein Ecosystem Science Laboratory Rubenstein School of Environment and Natural Resources University of Vermont. July 2007

56. Monitoring and Evaluation of Cyanobacteria in Lake Champlain Summer 2007. Mary C. Watzin, Susan Fuller, Cynthia May, Leman Bronson, Meghan Rogalus, Matthew Linder, and Rubenstein Ecosystem Science Laboratory Rubenstein School of Environment and Natural Resources University of Vermont. July 2008

57. Lake Champlain Phosphorus Concentrations and Loading Rates, 1990-2008. Eric Smeltzer, Vermont Department of Environmental Conservation; Fred Dunlap, New York State Department of Environmental Conservation; Marc Simoneau, Minstère du Développement durable, de l'Environnement et des Parcs. December 2009.

58. Reducing Phosphorus Runoff from Small Livestock Farms into Missisquoi Bay. James K. Bushey, Jeffrey E. Carter, Jonathan R. Chamberlin, and Sally A. Flis, Ph.D. Summer 2009.

59. Monitoring and Evaluation of Cyanobacteria in Lake Champlain, Summer 2008. Mary C. Watzin, Susan Fuller, Leman Bronson, Rebecca Gorney, and Lesley Shuster, Rubenstein Ecosystem Science Laboratory, Rubenstein School of Environment and Natural Resources, University of Vermont. August 2009.

60. An Environmental Accounting System to Track Nonpoint Source Phosphorus Pollution in the Lake Champlain Basin, Second Year Report. Lula Ghebremichael and Mary Watzin, UVM Rubenstein School of Environment and Natural Resources. May 2010.

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

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

By

Lula Ghebremichael and Mary Watzin
University of Vermont,
Rubenstein School of Environment and Natural Resources,
Burlington, VT 05401

May 20, 2010
Second Year Report

Final

Report Table of Contents

IV- EFFECTIVENESS OF AGRICULTURAL MANAGEMENT PRACTICES

V-LESSONS LEARNED

I- EXECUTIVE SUMMARY

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

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

The three farms studied all had phosphorus imbalances, which ranged from 4.9 lb/acre to 16.7 lb/acre across the farms. Though each study farm's case was different, critical sources of phosphorus imbalances common across the farms were: 1) feeding levels of supplementary dietary mineral phosphorus, 2) sources and types of protein and energy supplements, and 3) levels of productivity and use of homegrown feeds in animal diets. Overfeeding of mineral phosphorus supplements, low-productivity of homegrown feed (including grazing land) coupled with lower utilization of homegrown feed in animal diets, and a higher reliance on purchased protein and energy feed supplements to meet animal requirements for growth and production (milk, meat and others) were all contributors to the imbalances on these farms. Modeling results demonstrated that by implementing alternative management strategies for each farm, farm imbalance problems could be addressed while maintaining farm profitability. This model-based approach employed is widely applicable, as is the methodology of representing existing and alternative whole-farm system management strategies to evaluate and quantify the impacts of implementing these strategies on farm-level phosphorus flows and farm profitability.

The *WATERSHED-LEVEL PHOSPHORUS ACCOUNTING SYSTEM* section presents the details of a model-based phosphorus accounting system used to track phosphorus movement in an example watershed, the Rock River Watershed in the Missisquoi Bay lake segment. The Soil and Water Assessment Tool (SWAT) was successfully used to represent the hydrology, sediment, and phosphorus in the watershed, phosphorus being the main focus of the effort. Proportions of phosphorus loss contributed by subbasins of the Rock River Watershed and different landuses within each subbasin are presented. Moreover, because of variability in topographic, hydrologic, soil, and management factors, all nonpoint phosphorus sources do not contribute equally to water impairment. Some nonpoint sources contribute disproportionally higher phosphorus losses than others. These high risk areas for phosphorus loss are referred to in this report as Critical Source Areas for Phosphorus Loss. This model-based study identified and quantified Critical Sources Areas for phosphorus losses in the Rock River Watershed, and presented the extent and landscape characteristics of these Critical Source Areas for phosphorus loss.

Based on the modeling results, about 24% of the upland watershed area was producing more than 1.4 kg/ha of total phosphorus and about 80% of the total phosphorus load. The same 24% of the watershed area was also responsible for about 91% of the total sediment load. Critical sources areas for phosphorus loss had the following landscape characteristics less ground cover, erosive soil types, steep slopes, and phosphorus availability. Depending on the phosphorus reduction planned to achieve and availability of resources needed, other threshold values for phosphorus lose can be used to define critical source areas and would target different percentages of the watershed with high risk for phosphorus losses.

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

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

II-FARM-LEVEL PHOSPHORUS ACCOUNTING SYSTEM

INTRODUCTION

Areas with higher soil phosphorus build-up have a higher risk for phosphorus loading to water bodies. Some farm systems can contribute to higher soil phosphorus levels. Most of the dairy farms in Lake Champlain Basin are not able to produce enough grain for animal feed, therefore, energy and protein feed supplements are imported, primarily from the Canada and Midwestern U.S. This type of production system creates farms with a phosphorus imbalance resulting from more import of phosphorus (as animal feed supplements and fertilizer) than export of phosphorus (as crop and animal products). Farms with an imbalance have the potential to over apply phosphorus to the soil year after year, mainly in the form of animal manure, leading to an increased risk of soil phosphorus build-up and higher potential phosphorus losses to surface waters. Also, the amount of imported protein and energy supplements typically fed to cows is set based on the energy and protein requirements of cows, without careful consideration of the phosphorus content of these supplements. This phosphorus content is generally well beyond the phosphorus requirements for good health. Phosphorus not utilized by the cows enriches the manure and can result in a higher accumulation of phosphorus in agricultural fields where this manure is applied. Though detailed soil phosphorus test data specific to Rock River Watershed fields were not available, about 28% of sampled agricultural fields in Lake Champlain Basin were reported in the "*State of the Lake 2008*" to have high and very high soil phosphorus concentrations. High soil phosphorus concentrations are associated with higher phosphorus loss rates, and the phosphorus loss per unit area in the Rock River water is very high.

The objectives of the farm-level phosphorus accounting system were therefore to 1) estimate phosphorus balance status of farms in the Rock River Watershed, and 2) for those farms with phosphorus imbalances, to assess farm system management strategies that balance farm phosphorus inputs (in purchased feed and fertilizers) and farm phosphorus outputs (in milk, meat, or off-farm sales of harvested crops or other products). The farm-level phosphorus accounting system is designed to 1) identify the factors causing farm phosphorus imbalances (surplus), and 2) explore alternative management strategies that could address the root causes of the phosphorus imbalance. For this farm-level phosphorus accounting system project, a farm scale model, the Integrated Farm System Model (IFSM; Rotz and Coiner, 2006) was selected.

We used IFSM to account for farm phosphorus inputs and outputs on three Vermont dairy farms with varying farm systems (grass-based organic farm, fully confinement farm, and a mixed system farm with confined high-producing dairy cows and heifers that were grazed). The state of the phosphorus balance for each study farm was first calculated, and then alternative farm management strategies that might address phosphorus imbalances that have potential to worsen soil phosphorus accumulation and deteriorate water quality were explored.

IFSM MODEL DESCRIPTION

The Integrated Farm System Model-IFSM (Rotz and Coiner, 2006) is a comprehensive farm-scale model that simulates long-term environmental impact and farm profitability for various technologies and management strategies applied to a farm system (Figure 2-1). The model integrates models of crop growth, harvest, storage, feeding, animal (dairy or beef) production, and manure handling to determine the long-term performance and environmental and economic impacts of a farm enterprise. IFSM has been widely used in studying farm planning strategies mainly in the Northeastern and Central U.S. and Canada (Rotz et al., 1999; Rotz et al., 2001; Andersen et al., 2001; Soder et al., 2001; Rotz et al., 2002, Ghebremichael et al., 2007). The IFSM allows simulation of up to 25 years of weather data for a farm system. A complete description of the IFSM model can be found in Rotz and Coiner (2006).

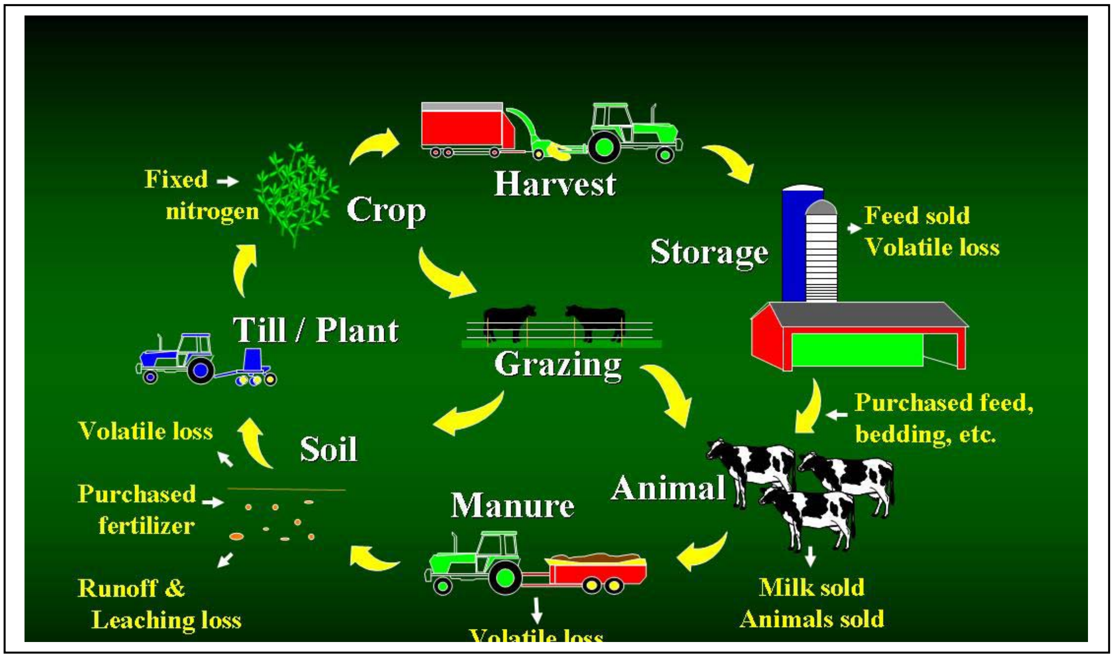


Figure 2-1. The various components of a farm system that are included in the Integrated Farm System Model-IFSM (adopted from online sources of USDA-ARS, University Park, Pennsylvania).

The IFSM model requires three input data files (farm, machinery, and weather input data) to represent a typical farm system. The farm data consist of detailed information that describes a farm enterprise. These are crop types and their area, generalized soil type and slope, type of animal (Holstein, Jersey, and others), number of cows of different ages, manure handling strategies, equipment and structures used, and prices of farm commodities produced, purchased feeds, and farm products sold off-farm. The machinery file contains data concerning the machinery used, including parameters related to machine type, size and associated costs. Finally, the weather file consists of weather data required by the IFSM model. These data include daily values of total precipitation, maximum and minimum temperatures, and solar radiation. The IFSM model requires daily weather data for a minimum of one year (365 days). A diagram of the IFSM user interface with selected input windows is presented in Figure 2-2 for illustration purposes**.** The IFSM model input windows include: crop and soil, tillage and planting harvesting, animal feeding, machinery, economic information, and manure handling information. For example, the crop and soil information window requires data related to types of crops grown, crop area, fertilizer and manure application to crops, and dominant soil types across the farm. The tillage and planting information includes data related to types of tillage equipment, dates of tillage, and planting dates. The harvesting information consists of data related to harvest time and appropriate method of harvest for crops (hay, silage, high moisture and dry grain). The animal and feeding information consists of data related to animal number, type, and size; milk production level; phosphorus feeding level; and list of supplemental feeds for purchase. Machinery information includes number and sizes of tractors and machinery used for various aspects of farm operations and the costs associated with the machinery. Economic information includes costs for crop establishment, commodities, feeds, labor, and custom operations. Finally, the manure information requires data on manure handling, storage, and application methods.

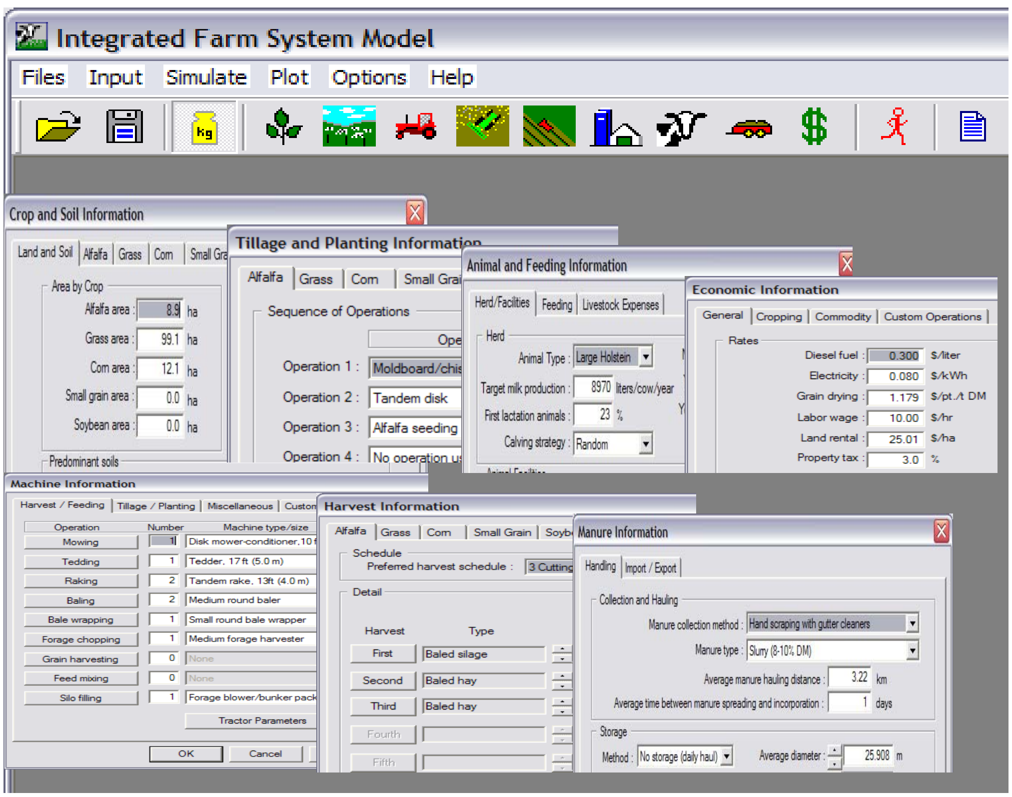


Figure 2-2. Integrated Farm System Model-IFSM window interface showing various input data requirements.

The model is comprised of different components that help estimate farm performance, profitability, and potential nutrient accumulation and loss to the environment. The IFSM model evaluates the performance of a farm enterprise by predicting crop yield and quality; on-farm feed, milk, and manure produced; feeds sold and supplemental feeds purchased; and resources expended, such as labor, fuel, and equipment use.

The IFSM model allocates feeds to the dairy herd based on individual animal requirements for maintenance, growth, and milk production and on the nutritive value of available feeds. To determine nutrient requirements, animals are put into different groups including, early-, mid-, late-lactating cows, dry cows, older heifers, and younger heifers. Animal feed sources for modeling can be from on-farm produced and/or supplemental off-farm purchased feeds. On-farm produced feeds may include forages (hay and silage) and grains, while off-farm purchased feeds may include energy and protein supplements, corn grain, and hay among others. When the nutrient requirements of the animal group is greater than the sum of nutrients contained in the feeds available on the farm, the model estimates supplemental feed purchases required to satisfy animal needs and maintain milk production.

The economic component of IFSM uses a simple enterprise accounting of production costs and incomes to compute net-return of a farm enterprise. The production cost includes costs of crop production, harvest, storage, feeding, and other production-related activities. The farm income includes receipts from sales of milk, animals, and crops.

The environmental component of IFSM predicts nutrient balances (phosphorus, nitrogen, and potassium) as well as off-farm erosion and nutrient losses. The farm phosphorus balance in the model is calculated by considering the import of phosphorus in feed and fertilizer and the export of phosphorus in milk, animals, and crops. The quantity and characteristics of phosphorus produced in the manure is calculated as a function of the quantity and phosphorus content of the feed consumed. In other words, phosphorus that is consumed but not used within the body for maintenance, growth, milk production, or reproduction will be excreted directly in manure.

STUDY FARMS

Three study farms located in Franklin County, Vermont, within Lake Champlain's Missisquoi Bay watershed were selected for our study. Two are within the Rock River watershed and the other is located slightly west of the Rock River Watershed. Study farms were selected based mainly on data availability and their representativeness of the farms in the study region.

Based on the USDA National Agricultural Statistics Service census of agriculture, about 42% of the cows in Franklin County are owned by small farm operations (SFO); 26% of the cows are owned by medium farm operations (MFO), and 31% of the cows are owned by large farm operations (LFO). Based on Vermont's farm size categorization, a farm with less than 199 cows is considered a small farm operation (SFO); farms with more than 200 but less than 699 cows are categorized as an MFO; and farms with 700 or more are categorized as an LFO. Based on this farm categorization, the percent of Franklin County farms categorized as SFOs, MFOs, and LFOs are about 82%, 13% and 5%, respectively. The large number of small farms, however, only account for about 42% of the total number of cows in Franklin County.

In addition to the great variation in herd sizes, farms also have different farm production systems. On some farms, cows are housed year round and fed a total mixed ration based on stored feeds (confinement operations). There is also some conventional pasture-based management, some organic certified dairies, and some farms with mixed production systems.

We selected three farms to model based on both the production system and the availability of data (Heather Darby, University of Vermont). These farms included: an organic certified farm that feeds cows with forage grown on the farm, a rotational grazing system, and some energy supplements (referenced in this report as the "organic farm"); a confinement dairy farm that produces excess corn silage for sale but purchases both energy supplements and the majority of its protein (referenced in this report as the "confinement farm"); and a high-yielding farm comprised of confined milk-producing cows and younger heifers that are grazed during the summer. This farm also purchases energy and protein supplements and is referenced in this report as the “High-yield-cows farm”). The different naming of the study farms, organic, confinement, and high-yield-cows, was introduced simply for identification purposes.

Organic Farm: The organic farm maintains 75 mature Holstein dairy cows and consists of 220 acres of (of which 36 rented) of crop area on predominantly medium loamy soils with slopes ranging from 3% to 8%. About 20 acres of silage corn are planted annually, with a rotation of one year corn followed by 5 years of grass-legume mix hay. The 200 acres are used for grass-legume mix forage, which is harvested with a combination of wrapped round bales, chopped haylage, and intensively managed rotational grazing. Oats and wheat are used as a first year nurse crop in reestablishing the grass-legume mix. This organic farm has been producing certified organic milk since 2003. The average milk yield of the cows housed in a stanchion barn is 16,000 lb/cow/year.

In addition to the 75 mature cows, the farm keeps 20 heifers <1yr old and 20 heifers >1yr old. All animals on the organic farm are grazed during the May to October grazing season using intensive rotational practices. Lactating cows are fed with corn silage, grass-legume mix and a purchased energy feed and mineral mix. The farm meets the protein requirements of the cows using the farm produced grass-legume forage mix. About 40% of the manure produced on the farm is used to establish the first year grass-legume mix and nurse crop, and the remainder is spread on fields following haying. The organic farm does not use any chemical fertilizer on any of the crops.

Confinement Farm: This farm maintains 135 mature Holstein dairy cows and consists of 360 acres of crops on predominantly deep and medium clay loam soils with slopes ranging from 3% to 15%. Crops grown on the farm include corn for silage (125 acres) and grass-legume mix (85 acres). Corn silage produced on farm is used as feed on the farm and also sold to bring extra cash income to the farm. The farm uses strip cropping and contour plowing to minimize erosion losses of sediment. The cows are housed in a tie-stall barn year round. The average annual milk yield of the cows was estimated to be 18000 lb/cow. The cows are fed a mixed ration of on-farm produced grass hay and corn silage, corn meal, a soy meal, canola and citrus mix, and a mineral mix. In addition to the 135 mature cows, the confinement farm maintains about 15 heifers >1 yr old and 38 heifers <1yr old. About 69% of the manure produced on the farm is applied to corn fields and the remaining manure is applied to the grass-legume mix fields. In addition, corn receives 200 lbs of 10-20-20/acre starter fertilizer (which is equivalent to 10 lb/ acre nitrogen; 20 lb/acre phosphate; and 20 lb/acre potash) and a side dress of nitrogen fertilizer amounting 175 - 200 lbs (21-0-0).

High-yield-cows Farm: The farm maintains 290 mature large Holstein dairy cows and consists of 455 acres of crop area on predominantly medium clay loam soils with slightly higher rocks and steepness compared to the two previously described farms. Crops grown on the farm include corn for silage (42 acres) and grass mostly for hay (413 acres). The soils and topography have been described as being "terrific for growing grass, but marginal for corn." In the future, the farm plans to phase out corn silage production and produce only grass-based forage and purchase corn silage and other feeds as needed. This farm does not own the farm equipment needed for tillage, forage harvesting, and storage. All farm operations are unique to this farm. The farm keeps 290 large Holstein cows in a freestall barn. These cows are fed a ration consisting of farm produced dry grass hay and corn silage, and supplemented with purchased corn silage, cotton meal, fine corn meal, high moisture corn, dried distillers grain, and a mineral and vitamin mix. In addition to the 290 mature cows, this farm maintains about 90 heifers >1yr old and 100 heifers <1yr old all housed in the barn in winter. Older heifers are grazed in the summer within rotating paddocks. Lactating cows are managed for a high milk yield averaging 25000 lb/cow annually through an improved milking management system. The improved milking management system involves a calm and consistent milking routing done three times daily. Manure produced on the farm is stored in a bottom loaded lagoon. 10% of this manure is spread on corn, 80% on grass, and 10% is exported from the farm. In addition, corn receives 25 lbs of 9-18-9/acre starter fertilizer (which is equivalent to 2.25 lb/ acre nitrogen; 4.5 lb/acre phosphate; and 2.25 lb/acre potash) and a top dress of 64 lb/acre of nitrogen.

FARM BASELINE MODEL REPRESENTATIONS AND VERIFICATIONS

To perform the modeling analysis, a baseline scenario for each of the study farms was created in IFSM. The baseline scenarios were based on data representing these dairy farms as gathered from a by a staff member in the UVM Extension system using an interview, a questionnaire covering the IFSM inputs, and information from existing nutrient management planning, animal feeding plans, and feed analysis of on-farm grown and purchased supplement feeds.

IFSM predictions were simulated over 25 years of weather. Hence, the simulated data represents the range of variation with mean and standard deviation values. When data are available, model-predicted mean farm parameters were compared with actual farm records obtained from each farm. The final acceptability of the model predictions was determined based on actual representations of farm records, that is, when actual data is close to the long-term mean values or falls within the standard deviation from mean value.

In this study, IFSM simulations of crop production, feed use, and manure production among others were simulated over many years of weather. Predicted average crop yields and nutritive contents were matched with crop yield data collected from farm records. IFSM predictions of feed use, production, and purchases for farms were also matched to the actual farm metrics. In addition, the same procedures were done to match the IFSM predictions of feed imports and exported to the actual farm records.

The term farm phosphorus balance (expressed in lb/acre), in the context of this report, represents the amount of farm phosphorus imported minus the amount exported excluding phosphorus losses associated with farm runoff and erosion. These losses were not included because 1) no measurements of farm runoff were available, and 2) there is a time lag involved in considering the phosphorus excess in feed consumed by cows, the amount excreted in manure, the application of manure to the soils, and losses to the environment. Hence, phosphorus balance was simply calculated by subtracting simulated phosphorus exports from phosphorus imports. These were predicted by the IFSM model based on the feeds produced, feed concentrates purchased, fertilizer-containing phosphorus purchased, and export from the farm of milk, animals, and farm-produced crops sold. When all farm-related factors are represented accurately, farm phosphorus balance predictions are expected to be closely related to actual values.

Verification of baseline phosphorus balance predictions was focused on these farm system parameters that govern predictions of nutrient flows and losses. Once these farm inputs and outputs were closely matched to the actual farm data, modeled phosphorus balances, potential phosphorus surplus (when phosphorus imports are greater than phosphorus exports) were analyzed for each farm.

Additionally, simulated baseline conditions include economic variables related to costs of production, farm incomes, and net returns for each farm studied. Because gathering of individual farms' economic data for all factors of production was difficult task, the economic simulations for most of the factors of production were based on long-term average annual values estimated under typical prices and costs of production. However, important predicted economic factors, such as, cost of feed purchased, income received from milk sales and few others, needed in the analysis of alternative management strategies, were made to closely represent for both the Organic and Confinement farms' financial record data. Because of data limitations, economic data could not be verified for the third farm. Also, to maintain confidentiality of the two farmers' economic records, actual farm costs and profits are not presented herein in this report. Note that the purpose of this modeling study was to determine the relative change in farm net-return resulting from implementing different management strategies. However, comparison of economic performance of farms should not be made across the study farms as appropriate economic data was not gathered to perform this kind of analysis. That type of analysis is beyond the scope of this study.

Organic Farm

Feed production and utilization: Table 2-1 shows average crop yields and nutrient content as predicted by IFSM and the data gathered from the farm. IFSM-predicted crop yields and nutritive contents, shown in Table 2-1, represent average values based on simulations over 25 years, with each year predicted as a separate observation. Predicted crop yields are measured in tons DM/acres. The nutritive contents, crude protein (CP) and neutral detergent fiber (NDF) of crops are measured as percent of dry matter (DM). Both CP and NDF factors are forage quality indicators.

IFSM predicted 25-year average yield of the grass-legume mix and its nutrient content values were closely matched to actual average yield data obtained from the farm. For corn silage production, predictions also closely matched the farm data. Even though predictions of corn silage quality (CP and NDF) could not be verified due to the absence of such data, they were in agreement with the "very low quality" description used by the extension personnel who gathered the farm data. Because corn fields do not get any nitrogen and starter phosphorus fertilizers (they get all nutrients from manure) the corn productivity is low in both quantity and quality. In fact, the farmer is planning to phase out the production of corn for the coming crop production year.

Feed utilization, the amount of feed used, on-farm produced and concentrated feed supplement purchased was evaluated for the milk production level of the farm. Table 2-2 and Table 2-3 represent details on cows ration and feed production and utilization, milk production for the organic farm. The average phosphorus feed level (0.41 % of DM ration; Table 2-2) is in excess by only 8% when compared to the NRC-recommended phosphorus levels (0.38% of DM ration; NRC, 2001).

The IFSM-predicted rations for each individual farm were compared to actual farm data available for sample feed rations (Table 2-2). The sample rations represent a typical ration mix for the non-grazing period and include daily rations fed, percent of forage feed fed, and other measurements. IFSM predicted dietary amounts of daily forage and the mount of energy supplement closely matches the typical ration data. Predicted total daily dry matter intake (DMI) and forage DMI per body weight for lactating cows was also comparable to the farm actual data for the animal size and milk production level of the farm. Based on NRC-recommended data, average DMI ranged between 41 to 44 lbs/cow/day for cows with a milk production level of 60 to 77 lbs/day and animal body weight of 1323 to 1433 lbs (NRC, 2001). The average body weight of lactating cows of this farm was 1325 lbs and the average milk production level of the herd was 60 lbs/cow/day. Therefore, the predicted DMI of 43.55 lbs/cow/day for lactating cows (Table 2-2) was reasonably within the NRC recommended values and the actual feed data gathered from the farm.

Overall, the baseline cow diet, which represents the current diet fed for the organic farm, constitutes more than 62% of high-quality forage for the non-winter season, and the forage contents are even higher during the grazing period as the farm employs a well-managed rotational grazing system. In addition, IFSM predictions of feed production and use, milk production, and purchases of feed supplements for the organic farm were compared with the actual farm metrics (Table 2-3). As shown from the actual farm data records, the farm produces high-quality forage (with CP = 20% of DM and NDF = 43% of DM) to meet its herd's protein requirement. Higher quality forages can be described as feeds that provide high levels of digestible nutrients and have the potential for high intakes while maintaining rumen health. Both CP and NDF values can be used as forage quality indicators. Typically, forages with CP value greater than 18% of DM and NDF value less than 46% of DM can be considered higher quality. Forage quality can be increased through more timely harvesting and/or grazing and improved management (in some cases involving increased nitrogen fertilization). The farm purchases an organic-mix of concentrates as energy supplement and minerals and vitamins mix (that contain phosphorus). Overall, the IFSM-predicted amounts of purchased feeds matched the farm record data well.

Table 2-1. IFSM-predicted and average crop yields and nutritive contents (CP and NDF) over a 25 year farm analysis and actual farm data for the Organic farm.

Crops	Yield, tones DM[1]/acres		CP[2], % of DM[1]		NDF[3], % of DM[1]	
	Predicted	Actual[4]	Predicted	Actual[4]	Predicted	Actual[4]
Grass legume mix[5], 200 acres (3 cuttings)	4.2	4.5	20.4	22.0	43.0	43.9
CORN, 20 acres (silage)	4.3	5.0	4.3	N/A	49.4	N/A

[1] DM = dry matter; [2] CP= crude protein; [3] NDF= neutral detergent fiber;[4] typical farm data based recent production and forage analysis data; [5] Grass legume mix represents total land used for grazing and harvesting hay and silage; N/A = data not available.

Table 2-2**.** IFSM-predicted and actual data on average daily diet composition of lactating cows during the non-grazing season for the organic farm.

	Actual Farm data	IFSM- Predicted
Quantity of each feed type (lbs DM/cow/day)		
Hay and silage (grass legume mix, corn)	28.75	26.7
Purchased energy supplement	14.08	16.6
Minerals and vitamins (Redman salt + KELP)	0.41	0.37
Total feed intake, lbs/cow/day	43.24	43.7
Forage portion of diet, %	66.5	61
Average body weight	1325	1347
Dry matter (DM) intake % body weight	3.26	3.23
Forage DM intake, % body weight	2.17	2.0
Phosphorus content of total ration, % DM ration	0.41	0.41

Table 2-3. IFSM-predicted farm feed production and utilization, and milk production for a 25 year analysis for the organic farm.

Parameter	IFSM-predicted annual values[1]	Actual farm data[2]
Forage, tones of dry matter (DM)		
Grass-legume mix	313 *(SD = 32)*	330
Corn silage	64 *((SD = 5)*	68
Grazed grass forage	154 *(SD = 16)*	168
Milk production, lbs/cow/year	16000 *(SD = 0)*	16000
Purchased feeds, tonnes of dry matter (DM)		
Energy supplement	170 *(SD = 30)*	200
Protein supplement	--	--
Mineral phosphorus and vitamin mix	5 *(SD = 0)*	7

[1] mean values based on 25 years of simulation; [2] based on two years actual data obtained from the farm records

Environmental and economic conditions: Predicted net phosphorus balance for the organic farm was 4.9 lb/acre for the baseline condition (Table 2-4). Based on the phosphorus import and phosphorus export predictions, the positive value in average phosphorus balance implies that more phosphorus is being imported onto the farm than exported off the farm. For the organic farm (with 4.9 lb/acre of surplus phosphorus), minimum intervention on some farm factors may be prescribed to reduce the net phosphorus balance further and achieve a zero net phosphorus balance. However, the magnitude of the surplus can generally be considered low compared to the other two study farms. The low phosphorus surplus is mainly attributed to the overall lower amounts of imported phosphorus feed from off-farm sources. As mentioned previously, this farm currently imports only organic energy supplements from off-farm sources. The farm grows high-quality forage (grass-legume mix) on the farm to meet the protein requirement of its herd. Typically, most energy supplements have lower phosphorus content compared to protein supplements.

With regard to the economic data included in the Table 2-4, the cost of purchased feed, the income received from milk sales and other factors were made to closely represent the organic farm's financial records. Hence, these data and other assumed costs of farm operations were used as baseline data and for comparing the relative changes in farm net-return resulting from implementing different management strategies.

Table 2-4**.** IFSM-simulated environmental and economic annual outputs for a 25 year analysis of the Organic farm

IFSM model output baseline	
Phosphorus imported, lb/acre	**11.9** *(SD = 0.9)*
Phosphorus exported, lb/acre	**7.0** *(SD = 1.0)*
Phosphorus balance (imported – exported), lb/acre	**4.9** *(SD = 1.0)*
Manure produced, tones DM	**233** *(SD = 4.5)*
P in manure, lbs	**2289** *(SD = 80)*
Cost and return expressed per mature cow, $/cow/year	
Milk and animal income	**4,365**
Total production cost	**2,674**
Machinery, fuel, electric, and labor cost	**520**
Facilities and other cost	**735**
Seed, fertilizer, and chemical cost	**44**
Land rental and property tax	**111**
Purchased feed	**1265**
Farm net return	**1691**
Standard deviation in net return	156

Confinement farm

Feed production and utilization: Similar to the approach taken for the organic farm, baseline model representations were compared with actual farm data. Results are presented in Tables 2-5, 2-6, and 2-7. Annual crop yield predictions by the model for the confinement farm compared well with the actual farm data (Table 2-5). Using the only available corn silage analysis data, IFSM-predictions of corn silage quality, CP and NDF were also verified, and they were found to be in agreement with the actual data. IFSM-predicted amounts of feed production and use, milk production, and purchases of feed supplements for the confinement farm were compared with the actual farm metrics (Table 2-6). Though there was no actual data on the amounts of each feed type used daily, use of detailed feed analysis data for all energy and protein supplements (Table 2-7) should provide reasonable predictions of each feed needed to meet animal requirements at the stated milk production levels. IFSM-predicted daily ration is presented in Table 2-8.

Under the current farming system (baseline condition), the dietary P level is 0.48 % of DM ration (Table 2-8); hence it is in excess by about 25% when compared to the NRC-recommended P levels (0.38% of DM ration; NRC, 2001).

Table 2-5. IFSM-predicted average crop yields and nutritive contents (CP and NDF) over a 25-year farm analysis and actual farm data for the Confinement Farm.

Crops	Yield, tones DM[1]/acres		CP[2], % of DM[1]		NDF[3], % of DM[1]	
	Predicted	Actual[4]	Predicted	Actual[4]	Predicted	Actual[4]
Legume with grass (canary) mix, 84 acres (3 cuttings)	5.1	5.0	21	22	49.3	52
Corn, 125 acres (silage)	7.1	7.5	7.3	7.31	43.6	42

[1] DM = dry matter; [2] CP= crude protein; [3] NDF= neutral detergent fiber;[4] typical farm data based on recent production and forage analysis data; [5] Grass legume mix represents total land used for grazing and harvesting high quality hay and silage

Table 2-6. IFSM-predicted farm feed production and utilization, and milk production for a 25 year analysis and actual farm data for the Confinement Farm.

Parameter	IFSM-predicted annual values[1]	Actual farm data[2]
Forage, tones of dry matter (DM)		
Grass-legume mix	213 *(SD = 20)*	N/A
Corn silage	809 *((SD = 116)*	858
Forage sold	331 *(SD = 163)*	360
Milk production, lbs/cow/year	18000 *(SD = 0)*	18000
Purchased feeds, tones of dry matter (DM)		
Corn meal/citrus supplement	181 *(SD = 7)*	180
Soy meal supplement	180 *(SD = 4)*	180
Canola meal supplement	71*(SD = 9)*	72
Mineral phosphorus and vitamin mix	10 *(SD = 0)*	12

[1] mean values based on 25 years of simulation, with each year as a separate observation; [2] based on two years actual data obtained from the farm, N/A = data not available

Table 2-7. Feed analysis information for on-farm produced and purchased feeds for the Confinement Farm

Nutritive Constituent	Units	Type of Feed Fed: Silage and Hay: grass Silage	Grass Hay	Corn silage	Energy and Protein Supplements: Corn meal/citrus	Soy meal	Canola meal
Crude protein	CP (%DM)	21.36	23.18	7.31	8.33	39.8	36.26
Protein degradability	DEGR (%CP)	78.77	70	60.96	70.56	45	53
Degradable intake protein	DIP (%DM)	16.82	16.22	4.81	5.88	17.91	19.22
Undegradable intake protein	UIP (%DM)	4.54	6.95	3.08	2.45	21.89	17.04
Acid deter. insoluble protein	ADIP (%DM)	1.2	1.61	0.47	0.67	1.19	1.92
	ADIP (%CP)	5.64	6.96	5.9	8	3	5.3
Neutral detergent fiber	NDF (%DM)	46.27	57.74	41.45	8.1	23.47	23.28
Net energy	N E (Mcal/kg)	1.27	1.43	1.51	1.96	2.06	1.85
Total Digestible Nutrients	TDN (%DM)	58.92	63.88	66.37	87	84.08	77.22
Phosphorus	P (%DM)	0.26	0.23	0.23	0.26	0.76	1.03
Potassium	K (%DM)	2.54	2.54	0.96	0.49	1.61	1.25

Table 2-8. IFSM-predicted average daily diet composition of lactating cows for the Confinement Farm.

Feeds parameters	Quantity
Quantity of each feed fed (lbs DM/cow/day)	
Hay and silage (grass legume mix, corn)	21.9
Corn meal/citrus supplement	9.1
Soy meal supplement	8.4
Canola meal supplement	2.6
Minerals and vitamins	0.41
Total daily feed fed ((lbs DM/cow)	42.4
Forage portion of diet, %	52
Average mature cow body weight	1483
Dry matter (DM) intake % body weight	2.8
Forage DM intake, % body weight	1.5
P content of total ration, % DM ration	0.48

DM = dry matter

Environmental and economic conditions: IFSM-predicted net phosphorus balance for the confinement farm was 13.6 lb/acre (Table 2-9). Based on the model predictions, about 54% of the imported phosphorus (in fertilizer and feed) is remaining on the farm. In other words, the amount of phosphorus imported to the farm as a supplemental feeds and fertilizer is twice the amount of phosphorus exported off the farm in milk and animals products and corn silage sold. The farm's phosphorus surplus, 13.6 lb/acre, is much higher than the phosphorus surplus from on the organic farm. Hence, changes in the current farm system may be needed to reduce the phosphorus surplus of the farm.

Also, important economic factors, such as, cost of feed purchased, income received from milk sales and other factors were closely matched to the confinement farm's financial records. Proper representation of these farm economic factors that were important in the analysis of alternative management strategies is helpful in determining the economic costs and benefits associated with implementing any change in farm systems.

Table 2-9**.** IFSM-predicted environmental and economic annual outputs for a 25 year analysis of the Confinement farm

IFSM model output	**Baseline**	
Phosphorus imported, lb/acre		**25.2** *(SD = 0.4)*
Phosphorus exported, lb/acre		**11.6** *(SD = 2.0)*
Phosphorus balance (imported – exported), lb/acre		**13.6** *(SD = 2.0)*
Manure produced, tones dry matter		**513** *(SD = 27)*
phosphorus in manure, lbs		**7494** *(SD = 312)*
Cost and return expressed per mature cow, $/cow/year		
Milk and animal income	**2,432**	
Income from corn silage feed sale	**306**	
Total production cost	**1,893**	
Machinery, fuel, electric, and labor cost		**473**
Facilities and other cost		**525**
Seed, fertilizer, and chemical cost		**79**
Land rental and property tax		**17**
Purchased feed		**799**
Farm net return	**845**	
Standard deviation in net return		130

High-yield-cow Farm

Feed production and utilization: Once again, baseline model representations were compared with actual farm data. Results are presented in Tables 2-10, 2-11, and 2-13. Annual crop yield predicted by the model for the high-yield-cow farm compared well with the actual farm data (Table 2-10). Using forage analysis data obtained from the farm, IFSM-predictions of forage qualities, CP and NDF and corn silage and grass hay were also verified and they are generally in line with the actual farm data. Moreover, IFSM-predicted amounts of feed production and use, milk production, and purchased feed supplements for the high-yield-cow farm were compared with the actual farm metrics (Table 2-11). Overall, predications reasonably represented the actual data. This high-yield-cow farm had detailed feed analysis data for all energy and protein supplements (Table 2-12); hence, the nutrient constituents of supplement feeds obtained from feed analysis were accurately represented in the model.

Dietary phosphorus as a percent of total feed intake was estimated using the detailed ration data obtained from the farm (Table 2-12). The dietary phosphorus level of this high-yield-cow farm is calculated to be 0.50 % of DM ration; hence, the 0.49% IFSM-predicted dietary phosphorus (Table 2-13) is close to the actual farm data. Based on this, the dietary phosphorus level of the farm is in excess by about 32% when compared to the NRC-recommended phosphorus levels (0.38% of DM ration; NRC, 2001).

Table 2-10. IFSM-predicted average crop yields and nutritive contents (CP and NDF) over a 25-year farm analysis and actual farm data for the High-yield-cow farm.

Crops	Yield, tones DM[1]/acres		CP[2], % of DM[1]		NDF[3], % of DM[1]	
	Predicted	Actual[4]	Predicted	Actual[4]	Predicted	Actual[4]
Grass forage 413 acres (3 cuttings)	4.1	5	17	17.1	51.9	51
Corn, 42 acres (silage)	6.1	6.5	8.3	7.3	43.8	43

[1] DM = dry matter; [2] CP= crude protein; [3] NDF= neutral detergent fiber;[4] typical farm data based on recent production and forage analysis data

Table 2-11. IFSM-predicted farm feed production and utilization, and milk production for a 25 year analysis and actual farm data for the High-yield-cow farm.

Parameter	IFSM-predicted annual values[1]	Actual farm data[2]
Forage, tones of dry matter (DM)/year		
1. Grass hay	1008*(SD = 200)*	1143
2. Grazed grass forage	213 *(SD = 13)*	Note[3]
3. Corn silage produced	209 *(SD = 41)*	245
4. Corn silage bought	748*(SD = 121)*	660
6. Milk production, lbs/cow/year	25000 *(SD = 0)*	25000
Purchased feeds, tones of dry matter (DM)/year		
7. Total feed concentrates	948 (*SD = 23)*	980
8. Cotton seed meal	143 (*(SD = 13)*	100
9. Corn meal	-	180
10. Corn meal & high moisture corn,	297 (SD =20)	
11. Dried distillers grain, high moisture corn, and mineral and vitamin mix	-	700
12. Dried distillers grain	486	-
13. Mineral and vitamin mix	23	13-19 [4]

[1] mean values based on 25 years of simulation, with each year as a separate observation; [2] based on two years actual data obtained from the farm; [3] 140 heifers pastured on 122.88 acres (these animals are not supplementary fed in summer, housed in barn in winter) and another 50 Breed Heifers are rotationally grazed on 50.21 ac (pasture average yield = 4 ton DM/acre these animals are not supplementary fed in Summer, housed in barn in winter); [4] fed to mature cows

Table 2-12. Farm record data of daily-lactating-cows-diet composition for the High-yield-cow farm.

Parameters	Units	Purchased: Cotton seed	Purchased: High Moisture Corn	Purchased: Corn meal	Purchased: Dried Distillers grain	Purchased: Mineral and vitamin mix	Purchased: Corn Silage	Produced: Hayledge	Produced: BMR Corn Silage
Daily ration	lbs/cow DM basis	2.76	4.68	3.89	11.32	1	7.98	12.11	9.25
Crude Protein	CP (%DM)	23.6	10.7	9.8	38.45		7.1	17	8
Neutral detergent fiber	NDF (%DM)	47.6	10.8	12.6	16.87		39.1	51.6	42.6
Net Energy	N E (Mcal/kg)	2.28	1.9	2.14	0.8782		0.77	0.68	0.76
Total Digestible nutrients	TDN (%DM)	98	92	82			73.2	65.7	72.4
Phosphorus	P (%DM)	0.73	0.36	0.34	0.6	6	0.22	0.38	0.25
Potassium	K (%DM)	0.26	0.39	0.31	1.23		0.94	3.36	1.38
Phosphorus fed from each feed	lbs/cow	0.020	0.017	0.013	0.068	0.060	0.018	0.046	0.023

Total phosphorus fed, lbs/cow	0.265
Percent of phosphorus in the total feed; % DM	0.50%

Table 2-13**.** IFSM-predicted and actual farm average daily diet composition of lactating cows for a High-yield-cow farm

	Actual farm data	IFSM- Predicted
Quantity of each feed fed (lbs DM/cow/day)		
Hay grass	12.11	8.2
Corn silage	17.2	18.9
Energy supplement	8.6	7.1
Cotton seed supplement	2.8	2.3
Protein and mineral supplement	11.3	12.8
Total feed intake, lbs/cow/day	52	49
Forage portion of diet, %	56	55
Average body weight	1484	1484
Dry matter (DM) intake % body weight	3.5	3.3
Forage DM intake, % body weight	2	1.8
phosphorus content of total ration, % DM ration	0.50	0.49

DM = dry matter

Environmental and economic conditions: IFSM-predicted net phosphorus balance for the High-yield-cow farm under the baseline condition is presented in Table 2-14. Based on the predictions, about 45% of the imported phosphorus is remaining on the farm. The farm phosphorus surplus, 16.7 lb/acre, is much higher than the phosphorus surpluses predicted for the organic and confinement farms (4.9 lb/acre and 13.6 lb/acre, respectively). Therefore, changes in the current farm system may be needed to achieve a reduction in the farm phosphorus surplus.

Note that predictions related to costs of production and net-return couldn't be verified for this particular farm due to the lack of economic farm data. The economic predictions presented here were based on typically cost of production and assumed prices of milk sale and feed purchases. These data were used as a baseline in comparing the relative changes in farm net-return resulting from implementing different management strategies.

Table 2-14**.** IFSM-predicted environmental and economic annual outputs for a 25 year analysis for the High-yield-cow farm.

IFSM model output	Baseline	
Phosphorus imported, lb/acre		**37.2** *(SD = 1.4)*
Phosphorus exported, lb/acre		**20.5** *(SD = 0)*
Phosphorus balance (imported – exported), lb/acre		**16.7** *(SD = 1.4)*
Manure produced, tones dry matter		**1022** *(SD = 27)*
phosphorus in manure, lbs		**12531** *(SD = 897)*
Cost and return expressed per mature cow, $/cow/year		
Milk and animal income	**4,038**	
Total production cost	**3,074**	
Machinery, fuel, electric, and labor cost		**332**
Facilities and other cost		**1434**
Seed, fertilizer, and chemical cost		**112**
Land rental and property tax		**69**
Purchased feed		**1087**
Farm net return	**964**	
Standard deviation in net return		70

ALTERNATIVE FARM MANAGEMENT STRATEGIES AND REPRESENTATIONS

Based on the farm simulation results with regard to environmental and economical aspects of the farm, potential alternative farm management strategies were developed for each farm. These potential alternative farm management strategies were developed when a phosphorus imbalance was identified for a particular farm. These strategies were focused generally on the two target farm factors presented below. In addition, the economic viability of the farms was maintained as an important consideration in assessing appropriate strategies that reduce surplus phosphorus.

I. Target on the feed phosphorus levels in the cows' diet. Phosphorus requirement guidelines for dairy cattle in the U.S. are available from the NRC publications (NRC, 2001). Strategies developed here may involve modifying supplemental animal diets to minimize overfeeding of phosphorus. The NRC recommends that the typical dairy cow diet contain between 0.32 and 0.38% phosphorus, depending on milk production of the animal fed. Reducing dietary phosphorus levels to match the NRC recommendations reduces both purchased feed phosphorus imports to a farm and phosphorus excreted in manure (Lanyon, 1992; Satter and Wu, 1999; Ebeling et al., 2002; Dou et al., 2002; Cerosaletti et al., 2004; and Ghebremichael et al., 2007).

II. Target the potential sources of protein and energy supplements on farms. Strategies that include growing forage and/or grains on the farm as an alternative to purchasing protein and energy supplements aim towards improving production and quality for local feeds thereby reducing the importation of phosphorus and promoting phosphorus reuse and recycling (Lanyon, 1992; Ghebremichael et al., 2007).

These alternative farm management strategies were also similar to the strategies developed under the Precision Feed and Forage Management (**PFM**) program of the Cornell University Cooperative Extension of Delaware County (**CCE**). The PFM includes a set of dietary nutrient and forage management practices aimed directly at targeting the root cause of phosphorus buildup on farms.

Alternative farm management strategies specific for each farm, were developed by involving extension personnel. They were based on the conditions on each farm and farm-specific future plans. For each farm, these farm management strategies were selected based on their effectiveness in directly targeting the root cause of phosphorus build-up on the farms while maintaining the profitability of the farms. In general, the management strategies reflect realistic farm management strategies for these farms and similar farms in the study region.

Alternative farm management strategies in the model were simulated by changing appropriate model input parameters. For example, for farms with excess phosphorus feeding rate, the phosphorus intake by animals in the model was set to the animal group phosphorus requirements following NRC-recommended values. Hence, this model simulation involved modifying animal diets so as to minimize overfeeding of phosphorus and to decrease manure phosphorus nutrient excretion.

EFFECTIVENESS OF FARM MANAGEMENT STRATEGIES

By comparing simulation results for current (baseline) and alternative management strategies, the effects of alternative management strategies were determined, including resource use, feed production and utilization, phosphorus mass balance, and the economic status of the farm. More attention was paid to potential changes in farm strategies that would reduce surplus phosphorus at minimal cost.

Modeling results for potential scenarios for each farm are presented in Tables 2-15 through 2-17. These data depict values predicted for the baseline scenario and changes from the baseline values for each alternative scenario and each respective farm. The changes were calculated as the differences in values between the alternative and baseline scenarios such that a negative change represents a reduction, and a positive change represents an increase in the predicted value compared to the baseline condition. Thus, the direction and magnitude of changes in economic or environmental factors resulting from implementation of an alternative scenario are shown.

Organic Farm

Using the current farming and cropping system, the organic farm was found to have a phosphorus surplus of 4.9 lb/acre. Overall, the organic farm's phosphorus imports are only slightly in excess of the phosphorus exports. The organic farm produces an adequate amount of high-quality grass-legume mix forage on the farm to meet the protein requirements of cows with a 16,000 lbs/year milk production level. Hence, this farm has done an excellent job in minimizing farm phosphorus inputs by producing enough high-quality forage on the farm. Therefore, only minimum intervention on dietary phosphorus may be prescribed if further reduction of farm phosphorus imports and a net zero (or near zero) phosphorus balance is desired.

***Scenario I*:** this scenario involves reducing dietary phosphorus levels. Compared to the 0.38% NRC-recommended dietary phosphorus level for high-producing dairy cows, this farm is currently overfeeding phosphorus by 8%. Hence, one potential strategy may be to further reduce the dietary phosphorus to the NRC-recommended phosphorus levels.

In the IFSM model, dietary mineral supplements are reduced until the dietary phosphorus is matched to the NRC-recommended phosphorus levels while maintaining other feed nutrient requirements of cows (Table 2-15). As mentioned in the model description, feed allocations and daily feed ration planning are made based on the nutrient contents of the feeds by making sure individual animal requirements for maintenance, growth, and milk production are met. Hence, reducing the dietary phosphorus rations to NRC (2001) recommendations resulted in a decrease in the amount of mineral phosphorus supplements purchased by 1 tons/yr for the organic farm, which reduced the amount of phosphorus imported. By reducing the dietary phosphorus by only 8%, the farm saved the money spent to buy mineral supplements, and the phosphorus balance was reduced by 3.2 lb/acre (Table 2-16), bringing farm's net phosphorus balance close to zero (± 1 standard deviation of model predictions). Overall, this strategy requires minimum changes in the farming system. However, diet manipulations of supplement concentrates (energy and mineral and vitamin mix supplements) to precisely match the dietary phosphorus to the NRC-recommended values should be made with the consultation of animal nutritionists, veterinarians, and feed industry in order to assure its proper implementation. When cows were fed a reduced-phosphorus diet, the amount of phosphorus in excreted manure was reduced (Table 2-16), a positive benefit to the environment. When field-applied manure contains lower concentrations of phosphorus, off-farm phosphorus loss will be reduced. A field-based study by Ebeling et al. (2002) showed a reduced soluble phosphorus loss in runoff from fields that received dairy manure with reduced dietary phosphorus level.

Scenario II**:** this scenario involved conversion of areas in corn silage production to high-quality forage production in addition to the strategy included in ***Scenario I***. Based on the farm's records, the production of corn silage has historically exhibited low yields. The low productivity of corn silage is presumed to be due to the lower soil productivity and absence of nitrogen and starter phosphorus fertilization. Also, for the coming production years, the farm intends to shift the land currently under corn silage production to high-quality forage production (grass-legume mix). Therefore, it was desired to assess how this landuse conversion would affect purchased energy supplements and ultimately the farm phosphorus imports in the feed.

By implementing the switch of land use from corn production to high-quality forage production on top of Scenario I, (***Scenario II*****),** IFSM predicted a slight increase in the amount of energy supplement purchases (Table 2-16) in order to offset the reduction in feed energy available in corn silage under the baseline and ***Scenario I*** conditions

(Table 2-15). There was no appreciable change in the farm's phosphorus balance due to this land use conversion. This could be due to the small increase in the amount of energy supplement imported. Therefore, the shift of corn land to high-quality forage production will have a minimal effect on the farm phosphorus balance. Because the operating costs assumed for producing corn are higher than those for producing grasses, the model also predicted an increase in the farm's net return as a result of reduced cost of production.

Table 2-15**.** IFSM-predicted average daily diet composition of lactating cows for grazing and non-grazing season for a randomly selected year, for all scenarios simulated for Organic farm.

	Baseline	**Scenario I**	**Scenario II**
	non-grazing season		
Quantity of each feed fed (lbs DM/cow/day)			
Hay and silage (grass legume mix)	21.1	21.1	26.4
Corn silage	5.6	5.6	0.0
Grazed forage	0.0	0.0	0.0
Purchased energy supplement	16.6	16.6	17.2
Minerals and vitamins	0.37	0.31	0.31
Total feed intake, lbs/cow/day	43.7	43.6	43.9
Forage portion of diet, %	61	61	60
P content of total ration, % DM ration	0.41	0.38	0.38
	grazing season		
Quantity of each feed fed (lbs DM/cow/day)			
Hay and silage (grass legume mix)	14	14	17.2
Corn silage	3.7	3.7	0.0
Grazed forage	11.7	11.7	11.7
Purchased energy supplement	14.0	14.0	15.0
Minerals and vitamins	0.37	0.31	0.31
Total feed intake, lbs/cow/day	43.8	43.7	44.2
Forage portion of diet, %	67	67	65
P content of total ration, % DM ration	0.41	0.38	0.38

Baseline = current farming system; Scenario I = dietary phosphorus reduction to match the NRC recommendations; Scenario II = Scenario I + corn land converted to high-quality grass production; DM = dry matter; P = phosphorus

Table 2-16. IFSM-simulated outputs for baseline scenario and changes in simulated outputs from the baseline scenario for alternative management scenarios for the Organic farm.

IFSM model output	Baseline[2]	Change in value[1] as compared to the baseline scenario *Scenario I*	*Scenario II*
Grass-legume mix, tones of DM	313	0	+157
Corn silage , tones of DM	64	0	-64
Grazed grass forage, tones of DM	154	0	0
Forage sold, tones of DM	0	0	0
Energy supplement, tones of DM	170	0	+3
Mineral and vitamin mix, tones of DM	5	-1	-1
Milk produced, lb/cow/year	16000	0	0
phosphorus imported, lb/acre	11.9	-3.2	-3.1
feed	11.3	-3.2	-3.1
fertilizer	0	0	0
precipitation	0.6	0	0
phosphorus exported, lb/acre	7.0	0	0
milk and animal	7.0	0	0
feed	0	0	+0.2
manure	0	0	0
phosphorus balance, lb/acre	4.9	-3.2	-3.3
Manure produced, tones DM	233	0	+7
phosphorus in manure, lb	2289	-303	-306
Cost and return expressed per mature cow, $/cow			
Milk and animal income	4,365	0	0
Total production cost	2,674	-7	-58
Machinery, fuel, electric, and labor cost	520	0	-50
Facilities and other cost	735	0	0
Seed, fertilizer, and chemical cost	44	0	-17
Land rental and property tax	111	0	0
Purchased feed	1265	-7	+9
Farm net return	1691	+7	+58
Standard deviation in net return	156	+3	+1

[1] change in value = alternative scenario value – baseline scenario value; [2] Baseline = current farming system; Scenario I = dietary phosphorus reduction to match the NRC recommendations; Scenario II = Scenario I + corn land converted to high-quality grass production; DM = dry matter.

Confinement Farm

Scenario I**:** this scenario involves reducing dietary phosphorus levels. The dietary phosphorus level of this farm is calculated to be 0.48 % of DM ration. Based on the individual feed analysis data gathered from the confinement farm, dairy diets were found to contain 0.37% phosphorus before supplemental mineral phosphorus was added. These diets already contained sufficient phosphorus for the milk production goal; therefore reducing mineral phosphorus supplements should be the first major step for this farm. This scenario requires relatively minimum strategic change in the overall farming system, therefore, this feeding approach was considered as part of all alternative farm management scenarios simulated.

By reducing the dietary phosphorus that the farm is currently overfeeding its cows, the mineral phosphorus supplements and total phosphorus imported to the farm were reduced significantly, by about 40% (Tables 2-17 and 2-18). In the IFSM model, the dietary mineral supplement was reduced until the dietary phosphorus is matched to the NRC-recommended phosphorus levels while also maintaining other feed nutrient requirements of the cows. This scenario reduces the amount of phosphorus in the excreted manure and saves money by buying less mineral phosphorus supplement.

To address the remaining surplus phosphorus on the farm, alternative sources of energy and protein feed were assessed in following scenarios.

Scenario II: this scenario assesses alternative sources of feed supplement to the strategies included in *Scenario I*. Under this broader scenario, however, three different alternatives were assessed – ***Scenario IIa, Scenario IIb,*** and ***Scenario IIc***.

Scenario IIa: this scenario involved utilizing part of the corn area, which is currently used to produce extra corn silage for sale, to grow canola seed to be used as a source of protein feed supplement. In order not to alter the whole feeding strategy, only the corn area that is currently used to produce the extra corn silage for sale was used to grow canola seed. All other farm factors were kept the same as in the ***Scenario I.***

Scenario IIb: this scenario involved utilizing part of the area currently used to produce extra corn silage for sale to rather grow a high-quality grass (legume-grass mix forage; CP = 19% of DM and NDF = 49% of DM) to be used as a protein feed supplement. Here the amount of forage fed to the cows was increased by selecting a high-forage diet option in the model. Dietary forage levels after implementation of the ***Scenario IIb*** was 75% of total ration DM for the farm. IFSM provides options for forage feeding: "high-forage diet" and "low-forage diet" (Rotz et al., 1999). When set at a high-forage diet in the model, the amount of a maximum amount of forage is fed, while meeting the energy and protein requirements with supplemental feeds and maintaining good rumen function. For the low-forage diet option, a minimum amount of forage is included in ration, while meeting a specified minimum roughage requirement. All other farm factors were kept the same as in the ***Scenario I.***

Scenario IIc: this scenario involves a more aggressive approach of combining the current system, which still allows the farm to produce corn silage for sale, and improving and increasing grass forage production. Currently, 125 acres (of the farm's 360 acres) are used for corn silage. Of the other 235 acres (360- 125), only 84 acres are used to grow grass forage. Hence, in this scenario, the area used in grass production was doubled, and productivity of grass was increased through improved management (i.e., timely harvesting). In addition, the cows were fed with a high-forage diet (forage level of 80% of total ration DM; Table 2-17) with precisely balanced dietary phosphorus levels (Table 2-17). For high-forage diets, a maximum amount of forage was fed while meeting the energy and protein requirements with supplemental feeds.

Model results from implementing ***Scenario IIa,*** showed a reduced phosphorus importation as the on-farm grown canola seed replaced some of the feed protein supplements (mainly canola meal) that the farm was purchasing. As a result, the farm's total phosphorus importation was reduced (Table 2-18). However, since the farm no longer sells corn silage, the amount of phosphorus exported from the farm was reduced resulting in a minimal benefit of this strategy with regard to reducing the overall phosphorus surplus on the farm. With respect to the economic effects of this strategy, there was a reduced farm net return due to both the losses of income from corn silage sale and the increases in cost of production needed in production and processing the canola seed (such as, crushing canola seed before it is mixed in the ration). The sale of the corn silage is benefiting the farm both as a source of income and in by increasing the phosphorus exportation from the farm. The potential risk of growing corn silage may be the erosion and associated phosphorus losses from the corn fields. However, this farm has implemented a set of management practices, including contour plowing and strip cropping system (of corn and grass), to address the potential high erosion from corn fields.

By implementing ***Scenario IIb,*** increased high-quality forage production (as alternative to growing canola seed in ***Scenario IIa)*** and increased utilization of forage in the cows' diet (Table 2-17), the amount of supplemental feed, mainly protein (soy and canola meals) purchased was dramatically decreased. As a result of this decreased importation of protein feed, the farm's phosphorus imports was further reduced compared to ***Scenario I***, and even compared to the ***Scenario IIa*** (Table 2-18). These model results are indicating a greater potential of ***Scenario IIb*** compared to ***Scenario IIa*** in reducing the amount of protein feed supplement required, phosphorus imports, and money spend in purchasing protein supplements. Compared to ***Scenario I***, the amount of phosphorus in manure excreted was also slightly reduced as the cows were fed more from homegrown-forage feed that is much easier to closely match to the NRC-recommended levels for cows with different milk production levels and stages of lactation.

The predicted cost of production under ***Scenario IIb*** was lower compared to the baseline cost of production due to lower costs of feed supplements. However, predicted farm net-income was lower than the baseline because the farm lost income coming from selling corn silage. For ***Scenario IIc***, expanded land in grass production and greater use of grass in the cow's diet, the farm phosphorus surplus was dramatically reduced and the farm profitability was increased. Note that this scenario included feeding cows with reduced dietary phosphorus, increasing the productivity of on-farm forage production while still producing corn silage under the baseline condition. Under this scenario the farm phosphorus balance (phosphorus imports - phosphorus exports) was predicted to be 2.8 lb/acre (Table 2-18). Considering the ± 2 lb/ acre standard deviation of model predictions for phosphorus balance, the farm's phosphorus balance is close to zero under this scenario.

In summary, based on the model simulation results, major reductions and possibly zero net-phosphorus accumulation on the farm, and eventually on the soils, are achievable when the confinement farm combined a reduced dietary phosphorus and increased productivity of on-farm forage production and utilization. Generally, as long as the costs saved by buying less feed supplements were higher than the costs of farm inputs and other operations required in increasing forage productivity, the profitability of the farm can be also maintained or even increased. The scenario analyses done in this study may not exhaust all possible alternatives but they do provide insights into the potential of alternative farming systems that help minimize farm imbalances while also maintaining the profitability of the farm.

Table 2-17**.** IFSM-predicted average daily diet composition of lactating cows for a randomly selected year, for all scenarios simulated for the Confinement farm.

	Baseline	**Alternative Scenarios**			
Feeds parameters		**I**	**IIa**	**IIb**	**IIc**
Quantity of each feed fed (lbs DM/cow/day)					
Hay and silage (grass legume mix, corn)	21.9	21.9	21.9	34.9	35.8
Corn meal/citrus supplement	9.1	9.1	9.0	8.2	4.6
Soy meal supplement	8.4	8.4	7.4	3.0	4.1
Canola meal supplement	2.6	2.6	0.8	0	0
On-farm produced canola seed	-	-	3.7	-	-
Minerals and vitamins	0.41	0.24	0.24	0.37	0.37
Total daily feed fed ((lbs DM/cow)	42.4	42.2	43.0	46.5	44.9
Forage portion of diet, %	52	52	51	75	80
P content of total ration, % DM ration	0.48	0.39	0.39	0.38	0.38

Baseline = current farming system; Scenario I = dietary phosphorus reduction to match the NRC recommendations; Scenario IIa = Scenario I + grow canola seed + no corn silage production for sale; Scenario IIb = Scenario I + grow high-quality forage + no corn silage production sale; Scenario IIc = Scenario I + keep the baseline corn silage production for sale + increase high-quality forage area and productivity; phosphorus = phosphorus; DM = dry matter basis.

Table 2-18: IFSM-simulated outputs for baseline scenario and changes in simulated outputs from the baseline scenario for the Confinement farm for alternative farm management scenarios.

IFSM model output	Baseline[2]	Change in value[1] as compared to the baseline scenario			
		Scenario I	**Scenario IIa**	**Scenario IIb**	**Scenario IIc**
Grass-legume mix, tones of DM	213	0	0	+325	+310
Corn silage , tones of DM	809	0	-343	-330	-5
Grazed grass forage, tones of DM	0	0	0	0	0
Forage sold, tones of DM	331	0	-331	-331	-30
Canola seed produced, tones of DM	0	0	+62	0	0
Corn meal/citrus supplement, tones of DM	181	0	-1	-9	-58
Soy meal supplement, tones of DM	180	0	+1	-139	-125
Canola meal supplement , tones of DM	71	0	-32	-66	-67
Mineral and vitamin mix, tones of DM	10	-4	-4	-1	-1
Milk produced, lb/cow/year	18000	0	0	0	0
phosphorus imported, lb/acre	25.2	-4.2	-5.4	-12.6	-11.1
feed	18.9	-4.2	-5.4	-10.1	-11.1
fertilizer	6.0	0	0	-2.5	0
precipitation	0.2	0	0	0	0
phosphorus exported, lb/acre	11.6	0	-3.2	-3.5	0
milk and animal	7.4	0	0.0	0.0	0.0
feed	4.2	0	-3.2	-3.5	0
manure	0.0	0	0	0	0
phosphorus balance, lb/acre	13.6	-4.2	-2.2	-9.1	-10.8
Manure produced, tones DM	513	0	+9	+91	+75
phosphorus in manure, lb	7494	-1494	-1366	-2295	-2690
		Cost and return expressed per mature cow, $/cow			
Milk and animal income	2,432	0	0	0	0
Income from forage sale	306	0	-306	-306	0
Total production cost	1,893	-17	-48	-192	-195
Machinery, fuel, electric, and labor cost	473	0	+53	+151	174
Facilities and other cost	525	0	0	0	0
Seed, fertilizer, and chemical cost	79	0	-13	+49	72
Land rental and property tax	17	0	0	0	0
Purchased feed	799	-17	-91	-392	-441
Farm net return	845	17	-255	-114	+195
Standard deviation in net return	130	3	+17	+25	12

[1] change in value = alternative scenario value –baseline scenario value; [2] Baseline = current farming system; Scenario I = dietary phosphorus reduction to match the NRC recommendations; Scenario IIa = Scenario I + grow canola seed + no corn silage production for sale; Scenario IIb = Scenario I + grow high-quality forage + no corn silage production sale; Scenario IIc = Scenario I + keep the baseline corn silage production for sale + increase high-quality forage area and productivity; phosphorus = phosphorus; DM = dry matter basis.

High-yield-cow Farm

***Scenario I*:** this scenario was implemented in order to reduce the excess dietary phosphorus levels that the High-yield-cow farm is feeding under the baseline feeding strategy. Based on detailed feed analysis data gathered from the high-yield-cow farm, dairy phosphorus diets was found to contain 0.50% DM compared to the 0.38% DM NRC-recommended dietary phosphorus level for high-producing dairy cows. By reducing the dietary phosphorus that the farm is currently overfeeding while also making sure the energy, protein, vitamins, and mineral requirements of the cows were met, the IFSM predicted that the farm can reduce mineral phosphorus supplement by 18% (2-19). This resulted in a 7% reduction in imported farm phosphorus (Table 2-20). Consequently, the amount of phosphorus in excreted manure can also be reduced. By reducing the amount of mineral supplement, the farm can also save some money as indicated in Table 2-20.

Because the high-yield-cow farm still has surplus phosphorus that must be addressed, scenarios that involve in looking at alternative sources of energy and protein feed supplements, ***Scenario II*a**, ***IIb***, and ***IIc,*** were assessed as a next step to reduce farm phosphorus imbalances. These scenarios add strategies of assessing alternative sources of feed supplements on top of the strategies included in ***Scenario I***.

Scenario IIa: this scenario involves phasing out corn production and improving forage production of the farm both in quality (CP = 19% of DM and NDF = 49% of DM) and quantity. Forage productivity (quantity and quality) can be increased through improved management, timely harvesting, and intercropping of grass and legumes crop varieties (grass-legume mix). As was mentioned previously, the farm has a plan to phase out corn production because the land currently growing corn silage is not ideal for this crop. Hence, this strategy was implemented in order to explore the benefits of increasing the quality and quantity of on-farm grown high-quality forage production as an alternative feed source to the farm and to help in reducing phosphorus inputs to the farm. All other conditions were kept the same as in ***Scenario I.***

Scenario IIb: this scenario increased the land area used for producing high-quality forage, and assessed the additional land that needed to be put in production in order to produce enough high-quality forage to achieve a balance between phosphorus imports and phosphorus exports. To accomplish this scenario, we assumed that rental land was available near this farm. This scenario was also designed following ***Scenario IIa*** to assess ways of addressing the surplus phosphorus that still remained on the farm. Under the ***Scenario IIa***, forage productivity was improved only on the land being utilized in forage production under the baseline condition. However, in ***Scenario IIb,*** the area used for growing forage was expanded until the farm produced enough high-quality forage to supplement the cow's feed with minimum phosphorus surplus. In ***Scenario IIb*** cows were fed with an increased level of forage in their diet (forage level of 63% of total ration DM; Table 2-19) compared to the baseline scenario (forage level of 55% of total ration DM; Table 2-19). This scenario was also intended to help find the extra land area needed for forage production if balancing farm phosphorus is desired through this strategy.

Finally, ***Scenario IIc*** involved a more aggressive approach of strategic changes in farm system by allowing all mature cows and older heifers to graze during the summer grazing period while also following the practices followed under ***Scenario IIa***. Hence, this strategy did not expand the farm areas represented under baseline condition. The forage productivity was improved and all mature cows and older heifer were allowed to graze during grazing season. Under the baseline scenario, only heifers were allowed to graze. From a management stand point, practicing rotational grazing with the entire 290 mature cows while expecting to milk three times a day may be challenging; however, this scenario provides a perspective to the potential economic and environmental benefits of expanding and improving grazing systems for this farm.

Table 2-19**.** IFSM-predicted average daily diet composition of lactating cows for a randomly selected year, for all scenarios simulated for the High-yield-cows farm.

	Baseline	**Alternative Scenarios**			
Feeds parameters		**I**	**IIa**	**IIb**	**IIc**
Quantity of each feed fed (lbs DM/cow/day)					
Hay grass	8.2	8.2	17.4	27	6.7
Corn silage	18.9	18.9	11.1	4.1	5.1
Grazed forage	-	-	-	-	19
Energy supplement	7.1	7.1	6.5	6.0	7.8
Cotton seed supplement	2.3	2.3	2.2	2.2	1.1
Protein supplement (DDG)	12.4	12.4	10.6	9.4	9.5
Minerals and vitamins	0.42	0.34	0.38	0.40	0.34
Total daily feed fed ((lbs DM/cow)	49.3	49.2	48.2	49.1	49.5
Forage portion of diet, %	55	55	59	63	62
P content of total ration, % DM ration	0.49	0.47	0.45	0.39	0.39

Baseline = current farming system; Scenario I = dietary phosphorus reduction in an effort to match to the NRC recommendations; Scenario IIa = Scenario I + no corn silage production + increase high-quality forage productivity; Scenario IIb = Scenario I + no corn silage production + rent and expand land to grow high-quality forage Scenario IIc = Scenario I + no corn silage production + increase high-quality forage productivity + intensive grazing; phosphorus = phosphorus; DM = dry matter basis; DDG= Dry Distillers grain

By increasing forage productivity on the farm, particularly the quality of forages produced on the farm, the model predicted a reduced need for purchased feed, mainly in the form of protein supplements (Table 2-20). Consequently, the farm was able to reduce the phosphorus surplus by 4.3 lb/acre compared to the baseline. Compared to the reductions achieved by ***Scenario I***, ***Scenario IIa*** reduced the phosphorus surplus by an additional 2 lb/acre for this farm. This strategy demonstrated the potential benefits of reducing the farm phosphorus excess and cost of production; however, it falls far short of completely addressing the phosphorus imbalance problem of the farm. This means the improvement made on forage production under ***Scenario IIa*** is not adequate as the ratio of area land used for forage production to number of cow is low. When land in forage production was expanded (by about 200 acres) and 738 tons of additional forage was produced and utilized for cow feed, under ***Scenario IIb***, the model predicted a reduced need for purchased feed, corn silage and concentrate supplements (Table 2-20). Consequently, the farm was able to balance the amount of phosphorus imports and exports and increase the net-return of the farm.

Table 2-20: IFSM-simulated outputs for baseline scenario and changes in simulated outputs from the baseline scenario for alternative management scenarios for the High-yield-cows farm

IFSM model output	Baseline[2]	Change in value[1] as compared to the baseline scenario			
		Scenario I	***Scenario IIa***	***Scenario IIb***	***Scenario IIc***
Grass forage, tones of DM	1008	0	+339	+339	0
Corn silage , tones of DM	209	0	-209	-209	-209
Grazed grass forage, tones of DM	213	0	0	0	+963
Corn silage purchased, tones of DM	748	0	-43	-485	-454
Grass Forage on rental land, tones of DM	-	-	-	+738	-
Energy supplement Corn meal & HMC tones of DM	297	0	-18	-47	+29
Cotton seed supplement, tones of DM	143	0	+1	-16	-67
Protein supplement (DDG), tones of DM	486	0	-82	-190	-187
Mineral and vitamin mix, tones of DM	22	-4	-2	-1	-4
Milk produced, lb/cow/year	25000	0	0	0	0
phosphorus imported, lb/acre	37.2	-2.7	-4.5	-15.6	-15.2
feed	36.3	-2.7	-4.3	-15.4	-15.0
fertilizer	0.2	0	-0.2	-0.2	-0.2
precipitation	0.7	0	0	0	0
phosphorus exported, lb/acre	20.5	-0.3	-0.2	-0.4	-0.9
milk and animal	17.4	0	0	0	0
feed	0	0	0	0	0
manure	3.1	-0.3	-0.2	-0.4	-0.9
phosphorus balance, lb/acre	16.7	-2.4	-4.3	-15.2	-14.3
Manure produced, tones DM	1022	0	+4	+86	+191
phosphorus in manure, lb	12531	-1066	-999	-1354	-3498
		Cost and return expressed per mature cow, $/cow			
Milk and animal income	4,038	0	0	0	0
Total production cost	3,074	-5	-99	-285	-343
Machinery, fuel, electric, and labor cost	372	0	+10	+84	-31
Facilities and other cost	1434	0	0	+3	0
Seed, fertilizer, and chemical cost	112	0	-13	+5	-7
Land rental and property tax	69	0	0	+68	0
Purchased feed	1087	-5	-96	-446	-443
Fencing cost	0	0	0	0	+138
Farm net return	964	+5	+99	+285	+343
Standard deviation in net return	70	+1	+14	+55	+6

[1] change in value = alternative scenario value – baseline scenario value; [2] Baseline = current farming system; Scenario I = dietary phosphorus reduction to match the NRC recommendations; Scenario IIa = Scenario I + no corn silage production + increase high-quality forage productivity; Scenario IIb = Scenario I + no corn silage production + rent and expand land to grow high-quality forage Scenario IIc = Scenario I + no corn silage production + increase high-quality forage productivity + intensive grazing; phosphorus = phosphorus; DM = dry matter basis; DDG= Dry Distillers grain

This strategy stays profitable as long as the costs of production required to increase grass forage productivity are lower than costs of feed supplements. Also, this strategy may not be a practical option if the availability of rental land is limited. When there is limited rental land available, another option may be to introduce grazing-based management system, ***Scenario IIc***, to the existing farm system with well-managed rotational grazing. By letting all cows and heifers graze on 235 acres of land during spring, summer, and fall grazing periods, the model predicted annual grazed forage consumption to reach 1176 tons (5 tons/acre; Table 2-20). On the remaining farm land (220 acres), the farm also maintained annual baseline forage production level (1008 tons) by improving the productivity (average yield of 4.6 tons/acre). By implementing the strategy of intensive grazing and improved forage management, the model predicted a reduced need for purchased feed concentrates and corn silage. As a result, the farm's phosphorus surplus was remarkably reduced compared to the baseline. Economically, the model also predicted an increase in net-profit because of a reduced cost of production. Note that a total annual grazing management cost was assumed to be $138/cow in this modeling study. However, this value can be replaced with appropriate data when actual costs of fencing, drinking watering system, seed, and others become available.

The alternative strategies assessed in this study may not include all possible alternative options. For example, if the scenarios, ***Scenario IIb*** and ***Scenario IIc*** are not practical because of unavailability of rental land and logistical limitations associated with implementing rotational grazing system with large number of cows (290 mature cows plus 190 heifers), another options may be to export excess manure produced on the farm in the form of compost. Detailed assessment of this option was beyond the scope of this study. Overall, the few scenarios assessed in this study provided insights into potentials of alternative farming systems that help minimize farm imbalances while also maintaining the profitability of farm.

SUMMARY AND CONCLUSIONS

The average farm phosphorus balance (phosphorus input – phosphorus output) on a ton per acre per year basis varied across the three farms studied (Table 2-21). Phosphorus imbalance and/or phosphorus surplus indicate that phosphorus inputs to the farm are greater than phosphorus outputs from the farm. The organic farm (75 cows with 16,000 lb/cow/year milk production level, and 220 acres of farm land) had the lowest phosphorus imbalance of 4.9 lb/acre per year. The confinement farm (135 cows with 18,000 lb/cow/year milk production level, and 360 acres of farm land) had a phosphorus imbalance of 13.6 lb/acre per year. The high-yield-cow farm (290 cows with 25,000 lb/cow/year milk production level, and 455 acres of farm land) had a phosphorus imbalance of 16.7 lb/acre per year.

Table 2-21**.** A summary of IFSM-predicted phosphorus balances of the study farms, Organic, Confinement, and High-yield-cow.

	Farms		
	Organic	Confinement	High-yield-cow
	75cow/220acre	135cow/360acre	290cow/455acre
Phosphorus imported, lb/acre	**11.9** *(SD = 0.9)*	**25.2** *(SD = 0.4)*	**37.2** *(SD = 1.4)*
feed	**11.3**	**18.9**	**36.3**
fertilizer	**0**	**6**	**0.2**
precipitation	**0.6**	**0.2**	**0.7**
Phosphorus exported, lb/acre	**7.0** *(SD = 1.0)*	**11.6** *(SD = 2.0)*	**20.5** *(SD = 0)*
milk and animal	**7**	**7.4**	**17.4**
feed	**0**	**4.2**	**0**
manure	**0**	**0**	**3.1**
Phosphorus balance*, lb/acre	**4.9***(SD = 1.0)*	**13.6***(SD = 2.0)*	**16.7***(SD = 1.4)*
Manure produced, tones DM	**233** *(SD = 4.5)*	**513** *(SD = 27)*	**1022** *(SD = 27)*
Phosphorus in manure, lbs	**2289** *(SD = 80)*	**7494** *(SD = 312)*	**12531** *(SD = 897)*

*phosphorus balance = imported – exported

When corrected for herd size, the farms' annual phosphorus balances were 14 lb/cow, 36 lb /cow, and 26 lb/cow for the organic, confinement, and high-yield-cow farms, respectively. The organic farm had the lowest phosphorus balance per cow compared to the two study farms because it has minimized its phosphorus inputs by producing most of its herds' feed on the farm. As described previously, the organic farm produces an adequate amount of high-quality forage on the farm, uses an intensive grazing system, and imports no fertilizer and no protein feed supplements. The farm has lower milk production lever per cow, but it has maintained its sustainability by producing a high-priced organic certified milk on a well-managed pasture-based farm system. For the organic farm, only a slight change on dietary phosphorus was needed to bring a net zero farm phosphorus balance.

On the other hand, the confinement farm had the highest phosphorus imbalance per cow compared to the other two farms because this farm accounted for less of the phosphorus that came in to the farm (in feeds and fertilizers) than the other two farms. The farming system of this farm can be considered as a mixed farming system integrating both animal and crop productions. In addition to the corn silage used by its herds, this farm currently produces extra corn silage for sale to generate income secondary to the sale of milk. The amount of phosphorus imported as a starter phosphorus fertilizer accounts for the 24% of the total farm phosphorus imports. Hence, major reductions and possibly zero net-phosphorus accumulation on the farm may be achieved by combining strategies that reduce phosphorus inputs in to the farm, both in starter fertilizer and in feeds.

Finally, the high-yield-cow farm had almost all inputs as feed, and had significant amount of phosphorus imbalance that may need to be addressed under the baseline conditions. Because of the small land to cow ratio, improving forage productivity on the existing land may not be adequate to help reduce the farms' phosphorus imbalance problem. For this farm with the smallest land to cow ratio, farm may be able to reduce its phosphorus imbalance by 1) reducing feed imports through increased forage production and utilization in the animal diet and by introducing an efficient and rotational grazing system, and 2) exportation of phosphorus in manure and compost (when feasible), among others. Note that the farm has done excellent job in increasing the conversion of feed phosphorus to phosphorus in milk products through its optimum milk production system involving improved milking management, an important way to help reduce farm phosphorus imbalance.

Finally, the Integrated Farm Systems Model, IFSM, was a useful tool in assessing the farm phosphorus balance of the study farms and in exploring alternative management solutions that help reduce the phosphorus imbalance problem with minimal cost. Such model-based studies done on a farm-by-farm basis are useful in complementing farm planners' efforts in exploring innovative farming systems that maintain or increase farm profitability while reducing nutrient phosphorus imbalance problems. IFSM model is a user-friendly tool and can easily be used by extension personnel and other agencies to assess impacts of farm system management changes on farm phosphorus balance and profitability. If use of IFSM model seemed infeasible, phosphorus inputs and outputs on farms may be monitored using a simple accounting system in order to assess and address farm phosphorus imbalance problems. To this effect, incorporation of a simple phosphorus accounting system of phosphorus inputs and outputs in the existing nutrient management planning effort may be beneficial in the comprehensive planning process. This will also reinforce the existing nutrient management planning to include efforts that address and target phosphorus imbalance problems by tracking phosphorus importations and phosphorus exportations of the farm in addition to tracking the movement of phosphorus on the fields.

III- WATERSHED-LEVEL PHOSPHORUS ACCOUNTING SYSTEM

INTRODUTION

Lake Champlain has historically exhibited eutrophication problems due to continuing phosphorus inputs from upstream areas (Lake Champlain Basin Study, 1979; Lake Champlain Basin Program, 2006; 2008). To address the excessive phosphorus loadings to the Lake and as part of the total maximum daily load (TMDL) requirements of the Clean Water Act, the United States Environmental Protection Agency (US EPA) and the Department of Environmental Conservation of both Vermont and New York States specified phosphorus reduction goals for segments of Lake Champlain that do not meet water quality standards (Lake Champlain Basin Program, 2002). Over 90% of phosphorus loading to lake segments not meeting targets is nonpoint source in orgin (Lake Champlain Basin Program, 2008). In order to make science-based decisions about management strategies needed to achieve the reduction goals, there is a critical need for scientific and systems-based approaches to determining the sources, transport, and potential for reduction of phosphorus throughout the Lake Champlain Basin.

The watershed-level accounting system uses a model-based approach to track the sources and movement of nonpoint phosphorus and to explore potential phosphorus reduction strategies at a watershed scale. Also, due to variability in topographic, hydrologic, soil, and management factors, all nonpoint phosphorus sources do not contribute equally to water quality impairment. Some nonpoint sources contribute disproportionally high phosphorus losses compared to others. This model-based study identifies areas that are high risk for phosphorus losses. Identification of these high risk areas for phosphorus losses can help guide managers current and future priority plans in allocating limited resources to address nonpoint phosphorus pollution and meet water quality standards required by the Lake Champlain TMDL.

Because of its wide and successful applications involving TMDL analysis and conservation practice assessment, the Soil and Water Assessment Tool (SWAT; Neitsch et al., 2002a) was selected for our project. We applied SWAT to the upper Rock River Watershed, Vermont, an agriculturally dominated watershed draining into Missisquoi Bay on the northeastern side of Lake Champlain. This bay is one of the Lake Champlain segments that do not meet the TMDL-specified target for phosphorus loading. The Rock River Watershed is also a high priority for watershed management activities due to high phosphorus loss per unit area.

This section presents:

- Details of SWAT model representations of Rock River Watershed, including data input used and model set-ups
- SWAT hydrology modeling, including sensitivity and analysis of hydrology input parameters and their uncertainty, model calibration, and validation processes
- SWAT sediment and phosphorus modeling, calibration, and validation processes
- Methods used in identification of critical source areas (CSAs), and
- The quantity and extent of CSAs of phosphorus loss resulting from the model analysis for Rock River Watershed.

SWAT MODEL DESCRIPTION

Soil and Water Assessment Tool (SWAT) is a hydrologic and pollutant model developed by the Agricultural Research Service of the United States Department of Agriculture (Neitsch et al., 2000a; 2000b). SWAT is a process-based, distributed, and continuous daily time-step watershed model, and simulates the transport of sediment, runoff, phosphorus, nitrogen, and pesticides as a function of land use at the subwatershed and watershed scales. The SWAT model has a long history of successful application in hydrologic watershed response and in the study of impacts of land management and climate on water quantity and quality in USA and internationally. Summaries of over 250 peer-reviewed SWAT publications are presented in Borah and Bera (2004) and Gassman et al. (2007). The SWAT model and its associated GIS interface have been integrated into the US Environmental Protection Agency's modeling framework of Better Assessment Science Integrating Point and Non-Point Sources (BASINS), which is being used in several states for total maximum daily load (TMDL) analysis (Diluzio et al., 2002).

The SWAT model allows a watershed to be divided into subbasins based on topographic criteria, with further subdivision of subbasins into hydrologic response units (HRUs) based on land use, soil type and slope combinations. SWAT allows the user to define management practices in every HRU. The user can also define the amount and timing of manure and fertilizer application in addition to other management operations. Geospatial data required for SWAT simulation include soil input map, digital elevation model, and land use coverage. Meteorological input data including precipitation, temperature, and solar radiation are also needed.

The model estimates relevant hydrologic components such as surface runoff, baseflow, evapotranspiration (ET), snowmelt, and soil moisture change for each HRU. SWAT uses runoff curve numbers to predict runoff volumes from daily rainfall and snow melt. The Soil Conservation Service's curve number is a function of the soil's permeability, land use, and antecedent soil water conditions. Curve numbers are recalculated daily, based on soil water content on that day. Ground water is calculated on a sub-basin basis, considering a shallow aquifer (contributes to stream baseflow) and deep aquifer (which does not contribute to streams) within the watershed. Algorithms are included in SWAT to represent water and nutrient movement in field with tile drainage. SWAT also includes snow melting and lake/wetland algorithms, which make the SWAT model a candidate in the study watershed where hydrology is significantly related to occurrence of overwinter snow accumulation, snowmelting during spring, and surface and baseflow contributions.

Erosion caused by rainfall and runoff is estimated for each hydrologic response unit using the Modified Universal Soil Loss Equation, MUSLE (Williams and Berndt, 1977; Williams, 1995). MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978). USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor. The runoff factor represents energy used in detaching and transporting sediment. This allows the MUSLE equation to be applied to individual storm events and runoff, which in turn is a function of antecedent moisture condition and rainfall energy.

SWAT represents phosphorus dynamics using six pools: three organic phosphorus pools (fresh [associated with crop residue], active, and stable; the latter two are associated with humus) and three inorganic phosphorus pools (labile [solution], active, and stable). Phosphorus may be added to the soil by fertilizer, manure, or residue application. Neitsch et al. (2002a and 2000b) details the various soil-phosphorus pools and interactions represented in SWAT. The organic phosphorus forms transform into inorganic phosphorus forms through the process of mineralization. Most of the mineral and organic phosphorus occurs in its adsorbed form. The inorganic phosphorus in the labile pool is in rapid equilibrium (several days or weeks) with the active pool. The active pool is in slow equilibrium with the stable pool. Phosphorus removed from the soil by plant uptake and runoff losses is taken from the labile phosphorus pool. The model estimates plant use of phosphorus using the supply and demand approach (Williams et al., 1984). Daily plant demand is estimated as a function of plant biomass and biomass phosphorus concentration. Depending on total plant biomass grown, or yield rate, the mass of phosphorus stored in plant biomass for each growth stage and the necessary plant uptake of phosphorus are determined. SWAT simulates crop growth and crop uptake of phosphorus for specified management, soil, and weather conditions. SWAT also simulates soluble phosphorus removed from the soil via runoff and particulate phosphorus removed with erosion.

In SWAT, urban/suburban areas with development (buildings, roads, and others) are treated differently from agricultural landuses because of their higher fraction of total area that is in impervious. The model differentiates impervious areas into two groups: the area that is hydraulically connected to the drainage system and the area that is not directly connected. For directly connected impervious areas, a curve number of 98 is used as a best initial estimate. For disconnected impervious/pervious areas, a composite curve number is calculated and used in the surface runoff calculations. Sediment and phosphorus losses from these areas are predicted using a linear regression equations (developed by USGS) or buildup and washoff mechanisms, similar to SWMM - Storm Water Management Model.

In this study, a version of the SWAT model with ArcGIS® interface (ArcSWAT 2.1, SWAT 2005) was employed. SWAT2005 has been linked with a set of recently developed tools useful to evaluate parameter sensitivity, aid in model calibration, and assess input parameter and model output uncertainty. With its detailed representation of the complex physical and hydrological processes and its GIS interface, SWAT model is a suitable tool in identification of critical source areas for runoff and phosphorus losses within a watershed. By using SWAT watershed modeling as a critical source area identification tool, a list of key site factors that contribute most to phosphorus generation and transport can be developed. Examples of site factors that may be important include: presence of runoff contributing areas, proximity to surface waters, slope, soil characteristics, land use, and existence of management practices and lack thereof.

SWAT model input Data and Sources

Geographical Information System GIS data were assembled based on currency, resolution, and consistency for use within the SWAT modeling environment. The landuse, soils, and topography data sets to be utilized for analysis in SWAT include:

Topography-Digital Elevation model obtained from online data source of Vermont Center for Geographic Information (VCGI) and of Canadian Digital Elevation Data (CDED).

Landuse: – developed by combining several land use data sources:

Digital land use/land-cover for the Lake Champlain Basin known as -LCB 2001: this data has a general land use classification for agriculture land use with no distinct identification for agricultural land uses, such as corn, hay, pasture, and others.

Crop field boundary data layer, the National Agricultural Imagery Programs' (NAIP) 2003, 1 m natural color orthophotographs and the USDA common Land Unit (CLU) boundaries obtained from the Farm Service Agency (FSA).

Pasture fields data layer mapped from NAIP 1m true color imagery acquired in 2003: obtained from UVM spatial analysis lab.

Farmstead location: GPS locations of active farmstead location data obtained from United States Department of Agriculture- Natural Resources Conservation Service (USDA-NRCS) GIS databases. These data were created by Reed Sims, A GIS specialist at USDA-NRCS, and field visits were made to ascertain their accuracy.

Soil data: SSURGO level soils map obtained from the national soils data for the Franklin County, VT(http://soildatamart.nrcs.usda.gov). Detailed soil properties obtained from the USDA/NRCS soil data mart available on line (http://soildatamart.nrcs.usda.gov/State.aspx).

Streams Network – United States Geologic Survey (USGS) digitized streams obtained from online data source of Vermont Center for Geographic Information (VCGI).

Weather data: the United States National Weather Service (air temperature and precipitation data) and Philipsburg climatic data obtained from Canadian government data Bank (Banque de données climatologiques). Banque de données climatologiques - données préliminaires, Québec, Ministère du Développement durable, de l'Environnement et des Parcs, Direction du suivi de l'état de l'environnement.

Observed (Measured) Data- Stream flow and water quality at the outlet of the Rock River near the border crossings of Vermont and Quebec, Canada, have been monitored by the Québec Ministère du Développement durable, de l'Environment et des Parcs (MDDEP). Stream flow data from the station # MDDEP 030425, located at Rivière de la Roche à Saint Armand in Canada (with 45.0217 Latitude ºN; 73.0161 Longitude ºW**)** was used in this study. Daily stream flow data at this station are available starting from October 1, 2001 to present. These data were used for model calibration and validation in the Rock River Watershed. The available data were divided into two data sets, with the first set (10/1/2001-9/30/2004) used for calibration, and the second set (10/1/2004-10/30/2007) used for validation.

STUDY WATERSHED DESCRIPTIONS

The overall area of the Rock River watershed at the Missisquoi Bay outlet is 152 km^2. The Rock River Watershed modeled in this study is the upper part of this watershed and encompasses an approximately 70.9 km^2 rural area located in the Vermont's far northwestern corner (Figure 3-1). This portion of the Rock River modeled is located between 3 and 10 miles inland from Missisquoi Bay. The study area has an average elevation of 101 meters, and is flat by Vermont standards. About 68% of watershed's slope ranges from 0 to 8% (Figure 3-2). The climate is humid with an average annual temperature of 6^0C and average annual precipitation of 1100 mm (based on 20 years data from meteorological station located at Enosburg, VT). Landuse in the Rock River watershed, shown in Figure 2, consists of 59% agricultural land uses (such corn, hay, pasture, small grains, and farmsteads), 5.6% developed (buildings and roads), 35% forest, 0.4% rangeland, and 0.6% wetland and water bodies. Soils in the watershed are of glacial origins dominated by mainly silt loam or silty clay loam types with about 48% and 45% classified under C and D hydrologic soil groups, respectively (Figure 3-2). These fertile periglacial lacustrine and alluvial soils support an intensive and increasingly consolidated dairy farming industry. Old tile drainages exist on crop fields throughout the watershed; currently about 90% of corn fields and 75% of the grass fields are estimated to have underlying old tile drainage systems (personal communication, Brian Jerose, WASTE NOT Resource Solutions, Enosburg Falls, Vermont). In Rock River Watershed, there are 34 small farm operations - SFO (3165 cows), 3 medium farm operations - MFO (836 cows) and 1 large farm operation - LFO (100,000 chickens). Based on Vermont's farm size categorization, a farm with 0-199 cows is considered a SFO; 200-699 cows form a MFO; and farms having more than 700 cows are LFOs.

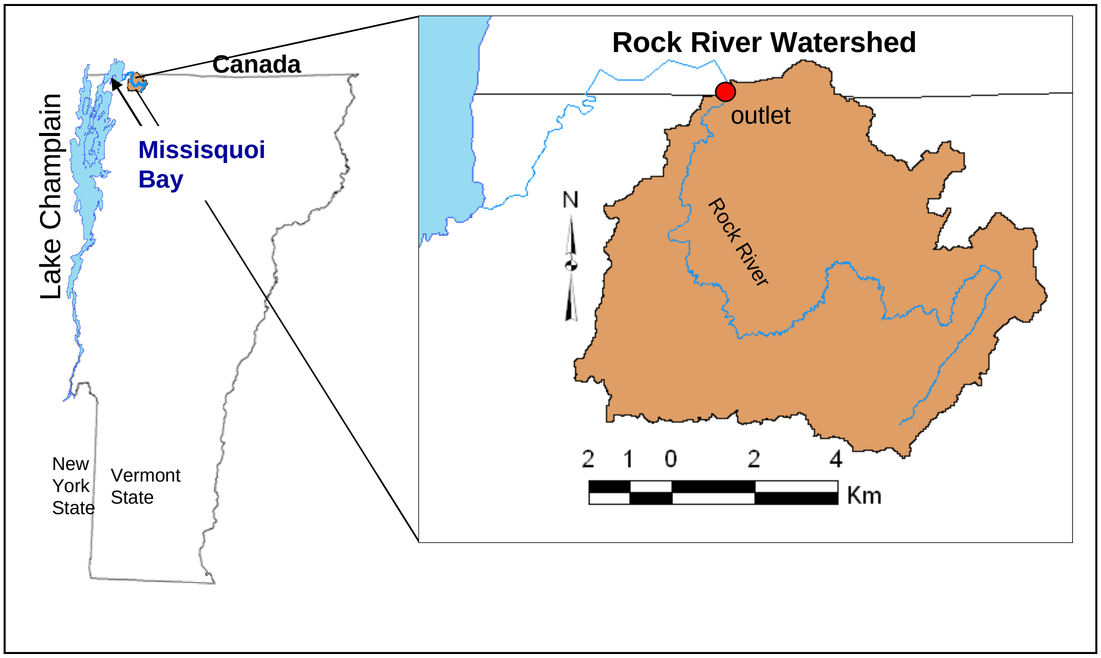


Figure 3-1. Location of Rock River Watershed modeled, Missisquoi Bay, and Lake Champlain at the USA/Canadian border.

SWAT Base input data representations

Baseline input data used to represent Rock River Watershed in SWAT (DEM, soil map and properties, and landuse maps with their sources and resolution) are described above, along with information about climatic and hydrological data. Land use coverage for Rock River Watershed was developed by combining several landuse data sources using GIS techniques. The land use data used are 2001 Lake Champlain Basin general land cover data (30 m national land cover database), the 2003 USDA's Farm Service Agency (FSA) Common Land Unit (CLU) GIS layer data of crop fields (hay and corn) and pasture, and digitized active farmsteads. The general land cover data available for this study watershed represents agricultural land use without identification to specific crop types. The CLU field boundary data specifically identifies agricultural crops, such as, hay, corn and pasture. The CLU crop field boundary data covers for most of the agricultural areas in the watershed in which owners participated in conservation programs and allowed sharing of their farm data. For these areas, the CLU field boundary of crop fields and digitized farmsteads were used to update the general land cover data. Representation of these areas in the model was made using appropriate land use types from the SWAT land cover database. Farmsteads were defined in the urban land use database and associated parameters were set to be consistent with typical farmstead characteristics. For agricultural areas without CLU field boundary data (and without specific crop type), the general land use cover data was used and represented using the SWAT generic land use type "Agricultural Land-Generic." Areas of agricultural land uses were 17% corn, 25% hay, 3% permanent pasture, 0.5% farmstead, 13.2 % agricultural crops that were not identifiable using CLU field layer. Areas for the other land use types are as described previously; 5.6% developed (buildings and open spaces and roads), 35% forest, 0.4% rangeland, and 0.6% wetland and water bodies. All these land uses were also represented in the model using appropriate land use types from the SWAT land cover database.

Processes included in the SWAT watershed delineation task are stream networks identification, watershed delineations, and sub-watershed delineations. These processes for the Rock River Watershed were performed using the watershed delineation tool built-in the SWAT ArcGIS® interface. A 10 m DEM data of the Rock River Watershed was used for this purpose. USGS digitized streams were also used to make sure the modeled streams closely matched these data. The monitoring station mentioned previously (Lat = 45.02^0N, and Long = 73.02^0W) was used to define an outlet of the Rock River Watershed and the watershed was delineated based on this outlet data. Inside the watershed, sub-watershed outlets were defined by GIS based on the generated streams. In this study, the watershed was divided into ten sub-basins representing the main tributaries and to match some of the Vermont Agency of Natural Resources -ANR synoptic sampling sites within the study watershed.

Within each sub-basin, unique hydrologic response units (HRUs) were defined based on the combinations of landuse, SSURGO level soil types, and four slope groups. Four slope groups, 0-3%, 3-8%, 8-15%, >15%, were purposely selected to match slope categories used in variety of farm planning purposes. In total, 5,577 HRUs were represented in the Rock River Watershed.

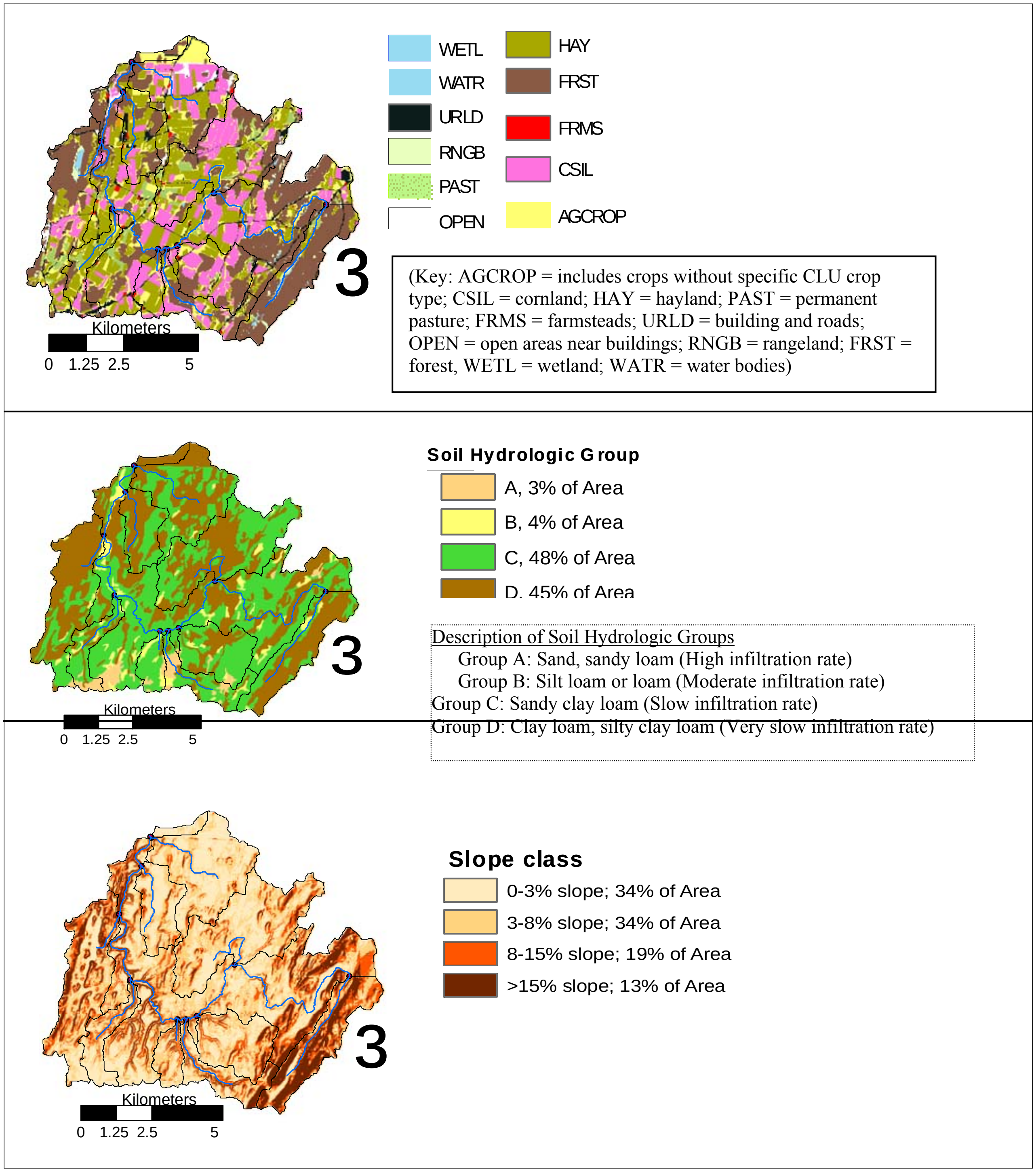


Figure 3-2: Maps showing slope, landuse, and soils of Rock River Watershed, Vermont.

SWAT management data inputs

Key SWAT inputs modeled pertaining to management include planting, tillage, harvesting, grazing, fertilizer and manure applications, and soil-phosphorus levels, as well as other management practiced in the watershed, such as tile drainage. Acquiring these data on a field-by-field basis for each farm in the study watershed was not possible because the data were not available and/or there were concerns related to disclosure of farmers' private information. Management input data were, therefore, based on typical management scenarios specific to crop type obtained from farm planners. These data were represented in the model using appropriate model parameters. This was also the case with regard to obtaining farmstead characteristics and management from each farm in the study watershed.

Due to the shorter growing season for corn grain, corn in this region is harvested as silage and utilized as a feed supplement in livestock production. Typically, corn is planted between May 1 and June 15 and harvested between mid-September and early October. May 10 and September 30 were used as corn planting and harvesting dates, respectively. Corn fields with heavy soils are generally plowed in the fall (October to November) and harrowed in the spring before planting. Other more well-drained soils are chisel-plowed in the spring and harrowed afterwards. Most farms use a low rate of P fertilizer as starter when planting corn. The rates are usually between 45 and 90 kg of phosphate per hectare.

Grass hay produced for livestock feed in this study area is predominantly orchard grass, with some timothy and bluegrass, and mixed with alfalfa or clover legumes. New seedlings of hay are typically planted during the first two weeks of May. Typically, harvests occur at the end of May, end of June, mid August, and sometimes a cutting in late September. Based on these data, May 1 was set in the model as the beginning date for grass growing; June 1, July 1, and August 15 were set as hay harvest dates. Based on similar data, grazing generally occurs on pasture lands starting around May 10 and continues until about November 1.

For crop production areas without specific CLU crop type (corn or grass), SWAT land cover type "Agricultural Land-Generic" was selected to represent them in model. Because no specific data was available, management scheduling (tillage, planting, manure application, harvest, and others) was based on heat units. Crop Heat Units (CHU) are temperature-based units that are related to the rate of development of crops. Overall, the quantity of manure applied to these crops on annual basis was equivalent to the amount applied to corn and hay. These data were represented in the model using appropriate model parameters.

Manure production in the watershed was estimated based on data concerning the number of animals, obtained from University of Vermont Extension and Vermont Agricultural Agency, and typical livestock manure production rates data compiled and reported by the American Society of Agricultural Engineers (ASAE, 1998). These data with detailed manure production calculations are presented in Table 3-1. Based on the data obtained from farm planners, manure application on corn fields occurs in the spring and occasionally in the fall. Many farmers spread manure on hay ground after the first (June 1st), second (July 1st), and third (Sept 1st) cuttings. Although manure application rates depend on individual nutrient management plans, application rates for corn averaged 75 Kiloliters/ha in both spring and fall. Spring applications are generally incorporated within 24 hours while fall applications are incorporated within 7 days. Overall, the quantity of manure applied to grass fields on an annual basis is equivalent to the amount applied to corn, except the total amount applied to grass is split into three applications after each hay harvest. This information was used in defining manure application rates and dates for each crop in the model.

Table 3-1. Manure production estimates (wet basis) for farms in the Rock River Watershed

Animal type	Total animal #	Live animal mass, Kg	Total animal mass, Kg	Manure Prod. Per 1000 kg live animal mass, Kg/day	Manure Prod., kg/day, wet
	column -A1	A2	A3 = A1*A2	A4	A5 = A4*A3/1000
LFO & MFO farms					
Mature cow	836	640	535,040	86	46,013
Heifers	335	320	107,200	86	9,219
SFO farms					
Mature cow	3,165	640	2,025,600	86	174,202
Heifers	1,203	320	384,960	86	33,107
Chicken	100,000	1.8	180,000	64	11,520
Goats	871	64	55,744	41	2,286

LFO = Large farm operation; MFO = medium farm operation; SFO = small farm operation

The SWAT model requires initial data related to soil phosphorus concentrations for the various HRUs modeled. Once the phosphorus pool is initiated, accounting of all additions (from fertilizer, manure, plant decay, and others) and subtraction (from plant uptake, runoff losses) is made continuously on a daily basis until the simulation period is ended (as mentioned in the model description section). Hence various HRUs will eventually have varying soil phosphorus levels depending on the type of crop, soil, slope, and management.

The initial soil phosphorus level is comprised of initial soluble phosphorus concentrations (SOL_LABP) and initial organic phosphorus concentrations (SOL_ORGP).

Because of the limitations in the soil test P data, a default value of 5 mg/kg for all landuses was used as the initial SOL_LABP value for the year of 1997, the initial year for the model simulations. For initial organic phosphorus, SWAT calculates initial organic phosphorus concentrations as a fraction (0.125) of the corresponding organic nitrogen (ON) concentrations, assuming an N:P ratio of 8:1. Organic N concentrations are estimated based on organic carbon (OC) values and a C:N ratio of 14:1. Organic C values are read from soil data. $SOL\_ORGP = 0.125*10^4\ (OC/14)$, where SOL_ORGP = soil organic P (mg/kg) and OC = organic carbon (%). The factor 10^4 is used to convert percentage to mg/kg. Once these initial values are used to start the model simulation, the model then simulates phosphorus loss and soil phosphorus levels by accounting for different forms of phosphorus in the soil.

HYDROLOGY SIMULATIONS

Sensitivity Analysis. Before the calibration of the hydrology modeling, a sensitivity analysis of input parameters was performed in order to determine the sensitivity of model outputs to changes in the values of model input parameters. By identifying input parameters that are sensitive, the number of parameters included in the calibration process was reduced and more effort could be focused on determining best values for the most sensitive input parameters. Because of the relatively large number of input parameters that may be involved in calibrating hydrology compared to sediment and phosphorus, sensitivity analysis in this study was performed only on the hydrology input parameters. All 26 parameters that may have a potential to influence hydrology predictions were included in the sensitivity analysis (Table 3-2). Sensitivity analysis was performed using a simulation period of 2001-2004, with a proceeding four-year period used as warm-up period. Figure 3-3 summarizes the sensitivity ranking of input parameters for stream flow prediction performances, which are determined by using the two object functions (OFs): 1) the OF was determined by calculating the sum of squared residuals difference between daily simulation flows of original run and the run after changing parameters value, and 2) the OF was determined by calculating the difference between the sum of squared residuals in daily observed flows and modeled flow at the watershed outlet.

CN2, Sol_Awc, and Esco that affect surface runoff were found to be among the most sensitive parameter. Of the parameters that affect ground water flow, the Gwqmn was found to be the most sensitive parameter. The importance of this groundwater parameter is not surprising because baseflow contributes important part of stream flow in this region. Moreover, TIMP and Smtmp, snowmelt processes parameters, were also identified to be among the most sensitive parameters as analyzed using the two the OFs. The importance of the TIMP and Smtmp is also relevant in this cold region where snowmelt is important component of the hydrology.

In summary, the sensitivity analysis provided ranks of influential hydrological input parameters. Also using the mean values, we were able to gain insights on those parameters that are more likely to affect model outputs and errors. As shown, only a handful number of parameters were found to have a mean value greater than 0.4, indicating changes in values of these parameters have greater impacts to the changes in the stream flow predictions. Hence, of 26 input parameters, only 12 input parameters with sensitivity mean values greater than 0.4 were included during model calibration process.

Table 3-2. Hydrology input parameters included in the sensitivity analysis.

Parameter	Description	Model process
Cn2	SCS runoff curve number for moisture condition II	Runoff
Esco	Plant evaporation compensation factor	Evapotranspiration
Gwqmn	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	Ground water/soil water
Timp	Snow pack temperature lag factor	Snow process
Sol_Awc	Available water capacity (mm/mm soil)	Soil water
Sol_Z	Soil depth	Soil water
Blai	Leaf area index for crop	Crop/infiltration
Gw_Revap	Groundwater ‘‘revap’’ coefficient	Evapotranspiration /ground water
Ch_K2	Effective hydraulic conductivity in main channel alluvium (mm/hr)	Losses from Channel
Alpha_Bf	Baseflow alpha factor (days)	ground water
Smtmp	Snow melt base temperature (^{0}C)	Snow process
Surlag	Surface runoff lag coefficient	Runoff
Slope	Average slope steepness (m/m)	Later flow
Gw_Delay	Groundwater delay (days)	ground water
Epco	Plant evaporation compensation factor	Evapotranspiration
Slsubbsn	Average slope length (m/m)	Time of concentration
Sol_Alb	Moist soil albedo	Evapotranspiration
Ch_N	Manning coefficient for channel	Channel Time of concentration
Sftmp	Snowfall temperature (^{0}C)	Snow process
Smfmn	Min. melt rate for snow (mm/^{0}C/day)	Snow process
Smfmx	Maximum melt rate for snow (mm/^{0}C /day)	Snow process
Tlaps	Temperature laps rate (^{0}C /km)	Temperature
Revapmn	Threshold depth of water in the shallow aquifer for ‘‘revap’’ to occur (mm)	Evapotranspiration /ground water
Biomix	Biological mixing efficiency	Soil water
Canmx	Maximum canopy index	Evapotranspiration
Sol_K	Soil conductivity (mm/h)	Soil water

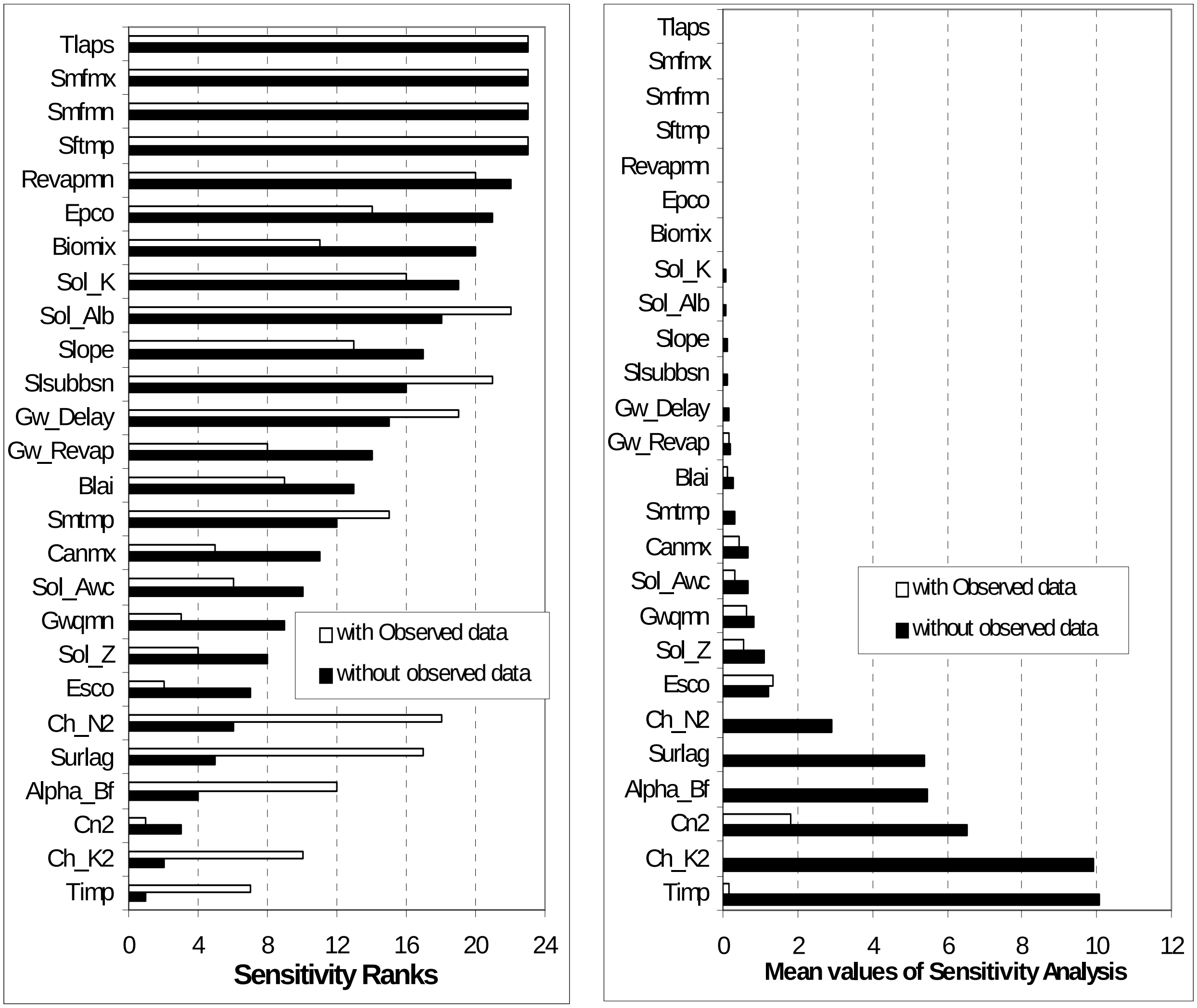


Figure 3-3. Sensitivity analysis results of hydrology input parameters. Note: description of parameters is presented in Table 3-2.

Calibrated Parameter Uncertainty. Stream flow was calibrated using the autocalibration optimization routine within SWAT (Van Griensven and Bauwens 2003) for the period of 2001 to 2004 on a daily basis by including the 12 input parameters identified during sensitivity analysis. Values of parameters for the optimum hydrograph are presented in Table 3-3; these parameter values provided the best solution of hydrology prediction (i.e. highest objective function values). This process also identified "good" parameter values for the 12 hydrologic parameters for which the objective function value was within the 95% confidence interval of the optimum hydrograph predictions. By simulating these "good" parameter values and identifying their maximum and minimum prediction intervals, hydrograph uncertainty was determined. Resulting hydrographs uncertainty is presented in Figure 3-4. This uncertainly of hydrology prediction is related to variation of input parameter values, which are identified to provide hydrology predictions within 95% confidence interval of the optimum predictions presented in Figure 3-5. In general, the uncertainty during the medium to high-flow predictions is small, as indicated by the narrow hydrograph (Figure 3-4). On the other hand, predictions during recession and low flow exhibited higher uncertainly (indicated by wider bounds. Wider uncertainty bounds indicate higher uncertainty of parameters values that govern the prediction of baseflow and recession parts of the hydrograph.

Table 3-3. Optimum Values of hydrology input parameters.

Parameter	Default values	Data ranges	Calibrated values
Cn2	landuse and soils dependent	±25%	-10[a]
Esco	0.95	0-1	0.63[b]
Gwqmn	0	±1000	750 [c]
Timp	1	0-1	0.11 [b]
Sol_Awc	soil dependent	±25%	-14.9 [a]
Sol_Z	soil dependent	±25%	-1.4 [a]
Blai	plant depend	0-1	0.45 [b]
Gw_Revap	0.02	±0.036	-0.025 [c]
Ch_K2	0.5	0-150	53.17 [b]
Alpha_Bf	0.048	0-1	0.45 [b]
Smtmp	0.5	±25%	-3.19 [a]
Surlag	4	0-10	0.30 [b]
Slope	slope dependent	±25%	--
Gw_Delay	31	±10	--
Epco	1	0-1	--
Slsubbsn	slope dependent	±25%	--
Sol_Alb	soil dependent	±25%	--
Ch_N	0.014	0-1	--
Sftmp	1	0-5	--
Smfmn	4.5	0-10	--
Smfmx	4.5	0-10	--
Tlaps	0	0-10	--
Revapmn	1	±100	--
Biomix	0.2	0-1	--
Canmx	plant dependent	1-10	--
Sol_K	soil dependent	±25%	--

[a] default values multiplied by this percentage value; [b] default values replaced by this value; [c] default value increased by this value.

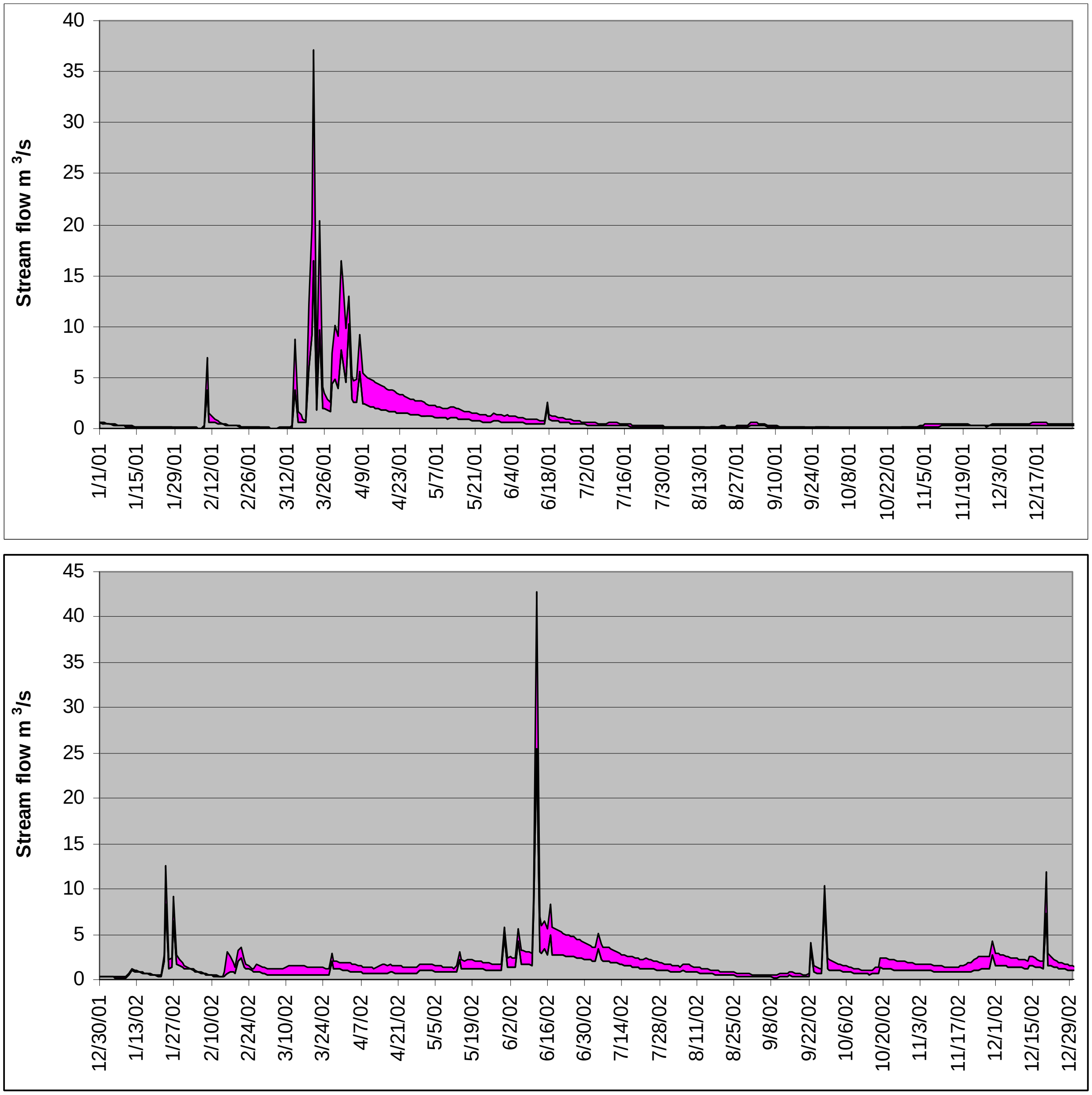


Figure 3-4. SWAT hydrology prediction uncertainty due to variations of input parameter values for Rock River Watershed.

Hydrology Simulations for the Calibration and Validation Periods. Model performance for calibrated stream flow predictions during 2001 to 2004 was assessed using descriptive statistics for measured and simulated runs. Nash-Sutcliffe coefficient, NS, scatter plots, and time series plots of simulated versus observed (measured) data were compared on a daily and monthly basis (Figure 3-5 and 3-6). Model predictions were then validated using the same performance measures for the period of 2004 to 2008. Results for daily and monthly stream flow predictions gave NS values of 0.60 and 0.74 for calibration periods, and 0.60 and 0.70 for validation periods. A review of the watershed-level, water quality modeling literatures have indicated that values of NS > 0.50 are generally considered satisfactory with median monthly NS values across the reviewed calibration literature of 0.79 value for stream flow (Moriasi et al., 2007). Overall, daily and monthly predictions obtained for stream flow are considered acceptable for this project.

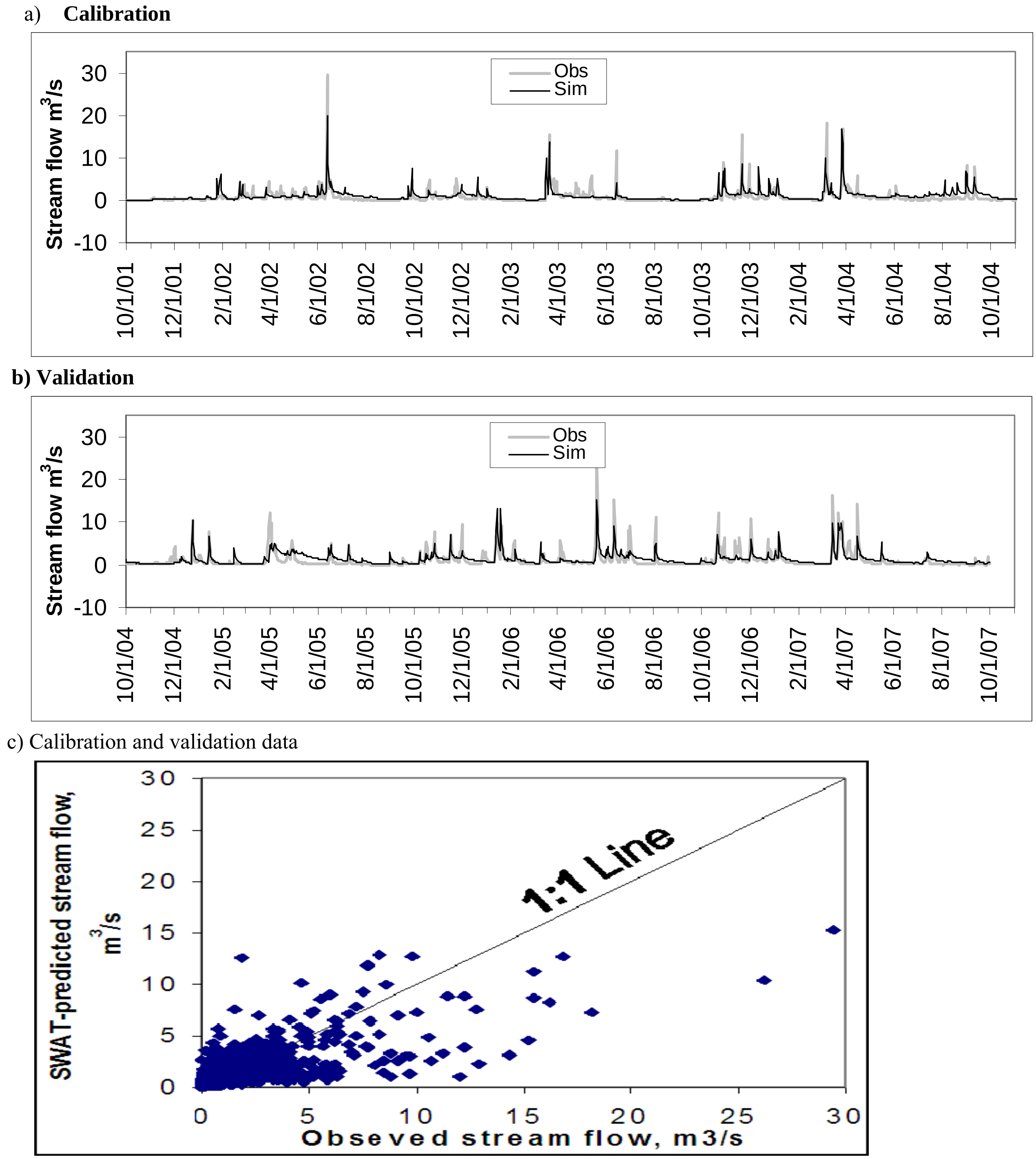
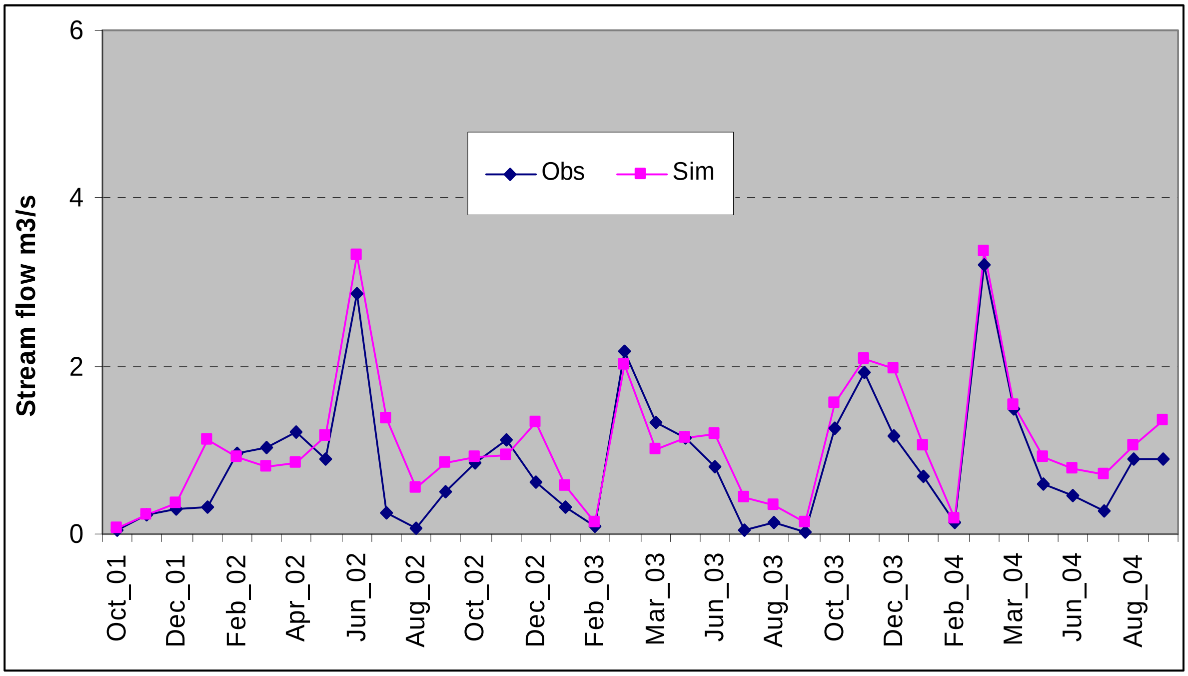


Figure 3-5. Time series plots of SWAT-simulated (Sim) versus observed (Obs, measured) for daily stream flow during (a) calibration and (b) validation periods, and (c) scatter plot using both calibration and validation period data.

a) Calibration



b) Validation

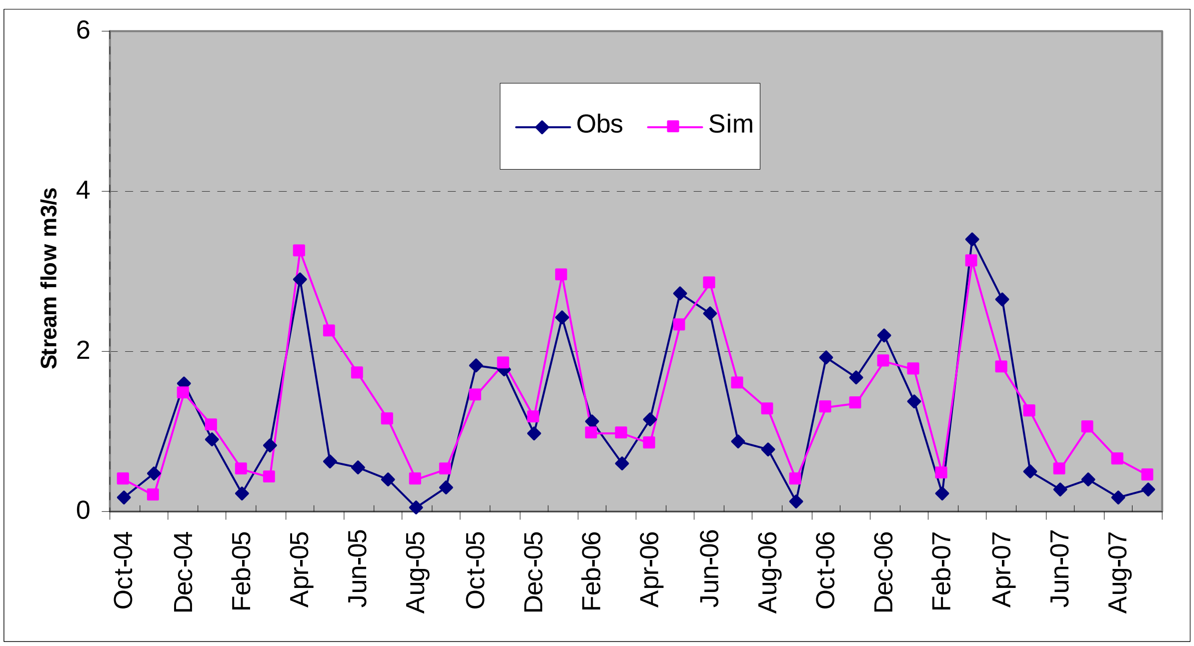


Figure 3-6. Time series plots of SWAT simulated (Sim) versus observed (Obs, measured) for monthly stream flow during (a) calibration and (b) validation periods.

In addition, model simulation of surface runoff was presented on the map shown in Figure 3-7. These results are based on 7-year average annual total surface runoff values; however, similar maps can be generated for any specific season and year of interest. Runoff predictions were classified into three runoff range groups to show the extents of areas with high, medium and low runoff. Areas shaded with darker color (blue) are showing higher runoff areas, while areas with lighter color (white) are showing lower runoff generating areas. As expected, high surface runoff was generated mostly on those areas with soils having low infiltration rates, such as, soils in C and D hydrologic groups. In addition, landuses, such as developed areas with low permeability, and corn fields from agricultural landuse were found to be among the watershed areas with higher surface runoff contributors. Results also show that runoff generated from the landscape is primarily governed by the combination of landuse and soils. This is in agreement with the runoff estimation method used in the SWAT model. SWAT uses a Curve Number (CN) method, which is based on the area's hydrologic soil group, landuse and cover, and hydrologic conditions, in estimating runoff volume. Once runoff is generated, slope and closeness to a stream govern the amount and the delivery timing of runoff to downstream waterbodies.

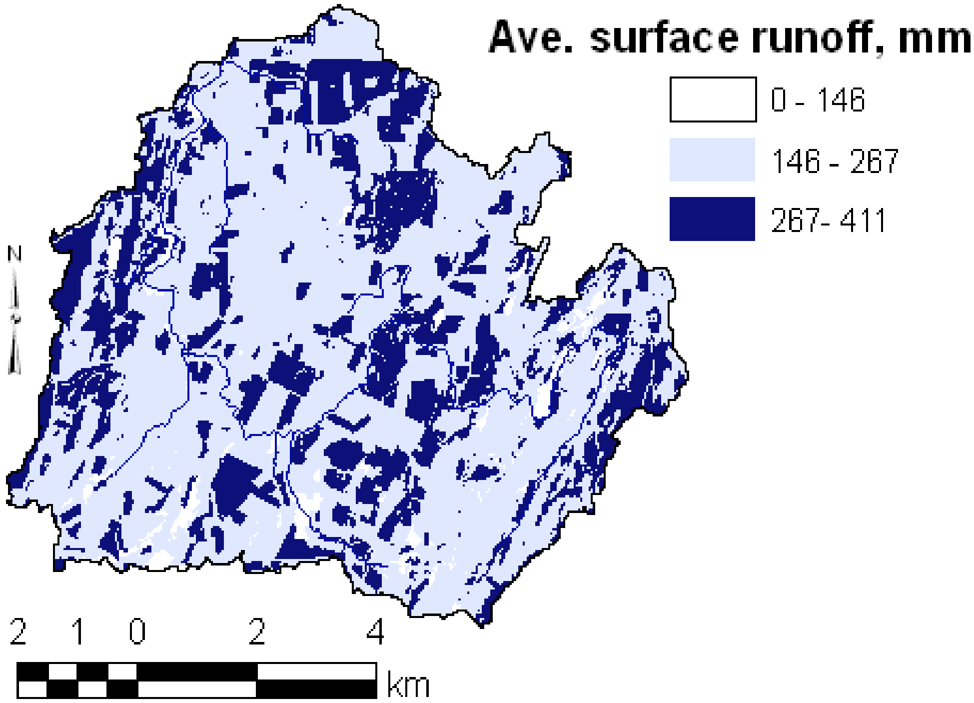


Figure 3-7. Spatial map of 7-year average annual surface runoff predicted by SWAT model for Rock River Watershed.

SEDIMENT AND PHOSPHORUS SIMULATIONS

Estimating Daily Sediment and Phosphorus Concentrations from Discrete Data. As mentioned earlier, stream flow and water quality at the outlet of the Rock River near the border crossings of Vermont and Quebec, Canada, have been monitored by the Québec Ministère du Développement durable, de l'Environment et des Parcs (MDDEP). Daily stream flow data collected were from the station # MDDEP 030425, located at Rivière de la Roche à Saint Armand in Canada (with 45.0217 Latitude ºN; 73.0161 Longitude ºW**).** Daily stream flow data are available from the station starting from October 1, 2001 to present, with data from 2008 to present subject to revision. Similarly, water samples collected are from the station # MDDEP 03040112, located at "de la roche à 0.8 km de la frontière des états-unis" in Canada (with 45.0243 Latitude ºN; 73.0168 Longitude ºW**).** The water samples have been analyzed for their sediment and phosphorus concentrations. Discrete sediment and phosphorus concentration data are, therefore, available from the station starting from October 14, 1998 to present.

Unlike stream flow data that were recorded daily using automated gauges, measured data for both sediment and phosphorus were available only as discrete data. These data are grab samples mostly taken during low or moderate flow conditions. These data represent discrete values of daily average concentrations for the days where samples were collected and were computed by calculating flow-weighted averages for all concentrations measured during any sampling day. However, since SWAT predications of sediment and phosphorus are provided as continuous daily outputs, it was desirable to have a continuous set of observed data to be used for model calibration and validation purposes. Therefore, various rating curves for generating continuous "observed" datasets from available discrete data were developed. Methods and steps followed for generating continuous "observed" data for both sediment and phosphorus are presented. The correlation of samples of sediment and phosphorus concentrations and corresponding stream flow data were also examined as suggested in Quilbe´ et al (2006).

Regression methods (rating curves) examined include:

1. Linear models: these models relate flow and concentrations in a straight line

   a) Simple linear model: $C = a + bQ$

   b) Log-log linear model that was used by Singh and Durgunoglu (1989): $Log(C) = a + bLog(Q)$

2. Non-linear relationships: these models relate flow and concentrations in a form of curve.

   Power relationship used by Assleman (2000): $C = aQ^b$

3. Cohn's Methods (Cohn et al. 1992) a more complex relationship of concentration that accounts for the effects of discharge, times, and seasonality:

$$Ln[C] = {}_2\beta_0 + \beta_1 \ln [Q/Q_m] + \beta_2 (\ln [Q/Q_m])^2 + \beta_3 \ln [T\text{-}T_m] + \beta_4 (\ln [T\text{-}T_m])^2 + \beta_5 \sin [2\pi T] + \beta_5 \cos [2\pi T] + \varepsilon$$

Where C = concentrations (sediment, phosphorus) mg/L, Q = flows rates m^3/s, T = times in years, Q_m, T_m = centering variables for Q and T. The a, b, c, d and β_i = models parameters estimated from data. ε = error term.

The suitability of these regression methods was determined using performance measures such as the following:

1. Scatter plots and time series plots (for visual observation)
3. Basic statistics (maximum, minimum, standard deviation-Sd, and mean).
4. Regression coefficient (r^2) and the Nash-Sutcliffe (NS) model efficiency coefficient (Martinez and Rango 1989) to assess the predictive power of the models

$$NS = 1-\left[\frac{\Sigma(obs-Pred)^2}{\Sigma(obs-Obs(mean))^2}\right]$$

Where Obs = is observed discharge and Pred = is modeled discharge. NS values typically range from negative infinity to one, with values of NS close to 1 indicating improved model performance and a value of zero indicating that the predicted values provide no better prediction that the mean of observed values.

Measured sediment and phosphorus concentrations and the corresponding flow data for the period of 2001 to 2008 are presented in the Figure 3-8. In general, the higher sediment, particulate phosphorus, and total phosphorus concentrations are related to higher flow and vice-versa. The correlation between sediment concentration and flow was 0.60; more than 60% of the variability of sediment concentration was explained by stream flow. The correlations for particulate phosphorus and flow and total phosphorus and flow were 0.69 and 0.61. However, it was difficult to find any correlation between the dissolved phosphorus and stream flow.

The performances of all rating curves examined are presented in Tables 3-4 and 3-5 for sediment and phosphorus. For sediment, of the various rating curves tested, a simple linear relationship was found to provide the best fit between sediment concentration and stream flow data with a NS value of 0.5. Hence, a continuous set of "observed" daily sediment concentration data was generated using this rating curve and daily flow data (Figure 3-9). Similarly, total phosphorus concentration and stream flow data were best fit to a linear rating curve with NS value of 0.51. The continuous set of daily "observed" total phosphorus concentration data generated using the rating curve and stream data (Figure 3-10) was used to estimate monthly total phosphorus load, which was later used for model calibration.

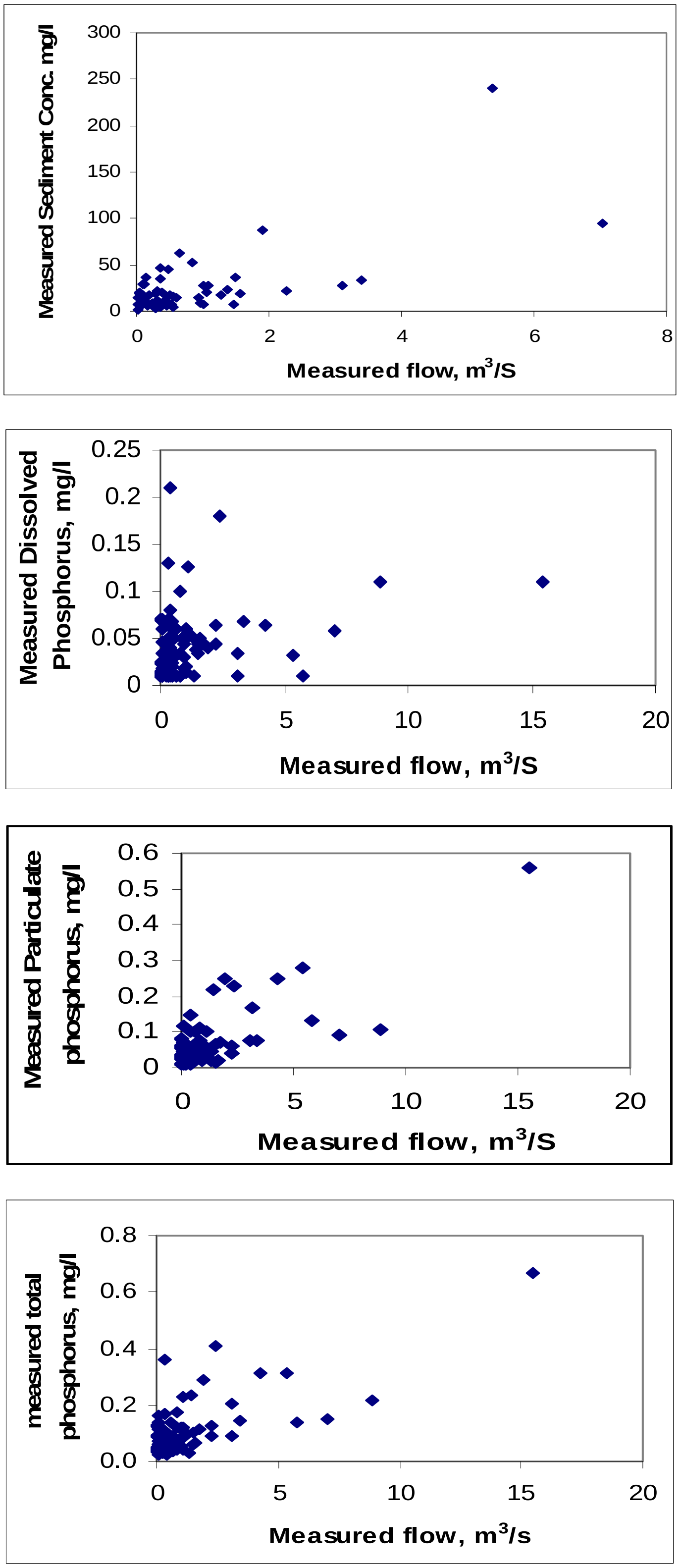


Figure 3-8. Measured sediment and phosphorus concentration and flow data for the Rock River Watershed during the period of 2001 to 2008.

Table 3-4. Comparison of the sediment (mg/l) rating curves.

Performance measures	Measured	Linear			Cohn's
		Simple linear	Log-log linear	Power	
r^2		0.49	0.20	0.2	0.43
NS		0.48	0.14	0.14	0.41
Mean	22.4	22.4	15.8	15.8	18.0
Sd	22.1	22.1	6.1	6.1	17.7
Maximum	240.0	141.2	36.3	36.3	136.8
Minimum	2.0	8.7	5.6	5.6	6.65
Model		(Sed)= 8.43 + 18.89* Q	Log (Sed)=1.31 + 0.30*log Q	Sed =20.30* $Q^{0.30}$	lnSed = 2.87 + 0.509 *Ln(Q/Qm) + 0.0976 *[Ln(Q/Qm)]^2 - 0.429* Cos(2πT)_1

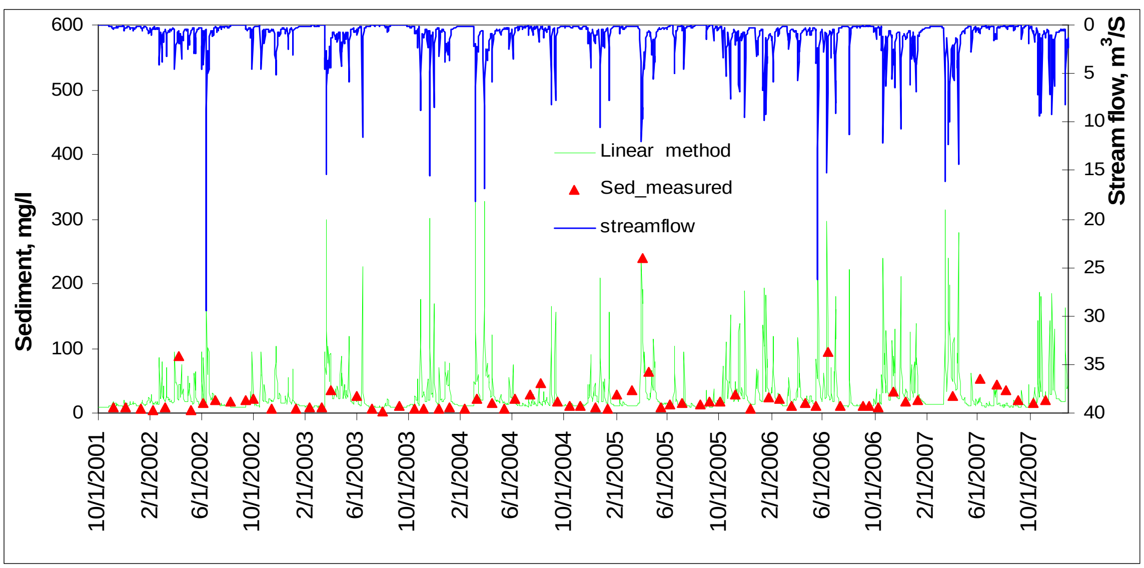


Figure 3-9. Stream flow and time series plots of sediment concentrations calculated using linear method versus sampled sediment concentration data.

Table 3-5. Comparison of the phosphorus (mg/l) rating curves.

Performance measures	**Measured**	**Linear**		**Non-linear**	**Cohn's**
		Simple linear	**Log-log linear**	**Power**	
Particulate Phosphorus					
r^2		0.57	0.14	0.15	0.40
NS		0.58	0.11	0.11	0.42
Mean	0.06	0.06	0.05	0.05	0.05
Sd	0.07	0.06	0.01	0.01	0.03
Maximum	0.56	0.45	0.09	0.09	0.23
Minimum	0.10	0.03	0.01	0.01	0.02
Model		(PP)= 0.033 + 0.027* Q	Log (PP)=-1.28 + 0.19*log Q	PP =0.052* $Q^{0.194}$	lnPP = -2.36 + 0.429 *Ln(Q/Qm) + 0.0534 *[Ln(Q/Qm)]^2 - 0.276* sin(2πT) – 0.576*Cos(2πT)
Dissolved phosphorus					
r^2		0.09	0.10	0.10	0.3
NS		0.09	0.11	0.11	0.3
Mean	0.04	0.04	0.03	0.03	0.03
Sd	0.04	0.01	0.01	0.01	0.02
Maximum	0.21	0.11	0.06	0.06	0.09
Minimum	0.01	0.04	0.03	0.03	0.01
		(DP)= 0.005 + 0.035* Q	Log (DP)=--1.46 + 0.16*log Q	PP =0.035* $Q^{0.164}$	lnDP = -5.02 + 0.272 *Ln(Q/Qm) + 0.0034 *[Ln(Q/Qm)]^2 – 1.62*(Ln(T-Tm) -0.26*(Ln(T-Tm)^2 -0.49* sin(2πT) – 0.31*Cos(2πT)
Total phosphorus					
r^2		0.51	0.19	0.19	0.48
NS		0.51	0.16	0.16	0.50
Mean	0.10	0.10	0.08	0.08	0.09
Sd	0.09	0.07	0.02	0.02	0.05
Maximum	0.67	0.56	0.16	0.16	0.35
Minimum	0.02	0.07	0.02	0.02	0.03
Model		(TP)= 0.0683 + 0.032* Q	Log (TP)=-0.72 + 1.01*log Q	DP =0.096* $Q^{0.184}$	lnDP = -1.70 + 0.38 *Ln(Q/Qm) + 0.035 *[Ln(Q/Qm)]^2 +0.47*(Ln(T-Tm) +-0.06*(Ln(T-Tm))^2 -0.35* sin(2πT) – 0.59*Cos(2πT)

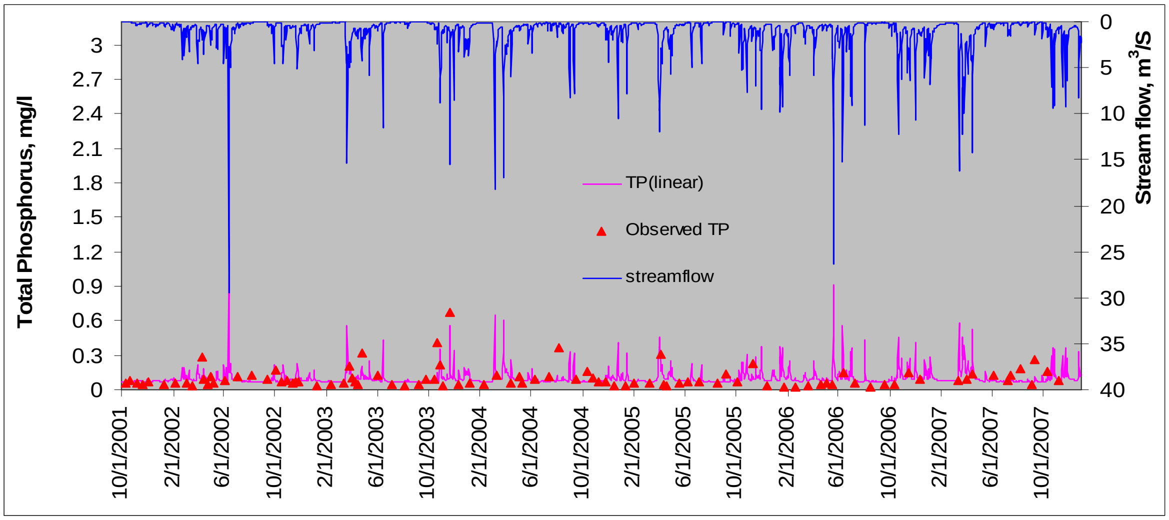
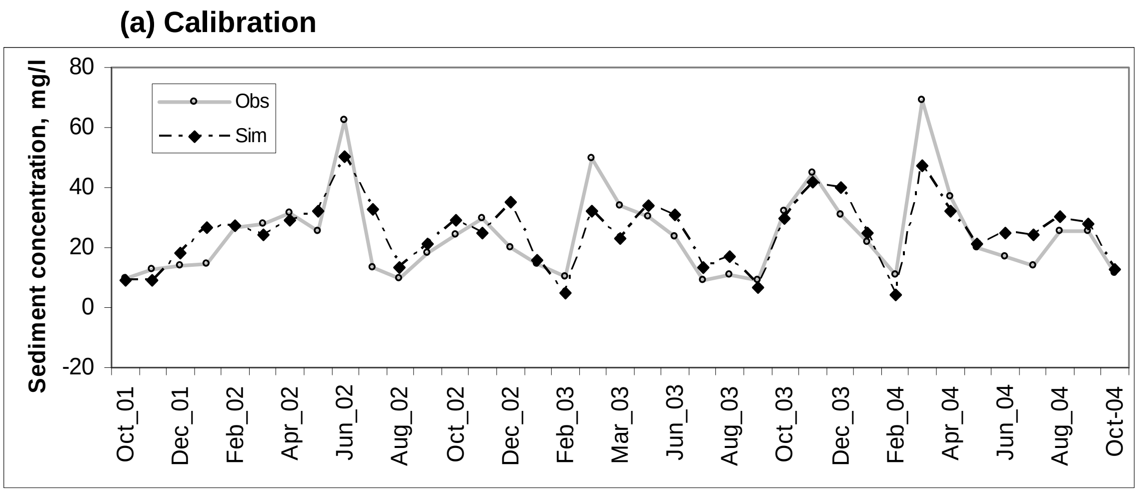


Figure 3-10. Stream flow and time series plots of total phosphorus concentrations calculated using linear method versus sampled total phosphorus concentration data.

Calibration and Validation of Sediment and Phosphorus Predictions. The continuous set of daily "observed" sediment concentration and total phosphorus load were used for model calibration. For both sediment and phosphorus, predictions were manually calibrated for the period of 2001 to 2004, and model predictions were then validated for the period of 2004 to 2008.

For sediment concentrations, NS values on a daily and monthly basis were 0.4 and 0.7 respectively, for the calibration period; and the NS values for the validation period were 0.4 and 0.6 for daily and monthly predictions. Graphs comparing monthly predictions and observed sediment concentrations are presented in Figures 3-11 and 3-12. Though daily sediment concentration predictions were difficult to match to observed data, monthly sediment concentration predictions were reasonably close to the observed data. Overall, monthly sediment predictions were reasonably close to the observed data. For total phosphorus, only monthly load predictions were compared to the observed data (Figure 3-13). Based on this comparison, NS values for monthly total phosphorus load predictions were 0.7 and 0.60 for the calibration and validation periods respectively.

Overall, SWAT did a satisfactory job in predicting total phosphorus load at the outlet of the watershed with only 2% error of over-prediction for the calibration period and with a 10% error of under-prediction during validation period.



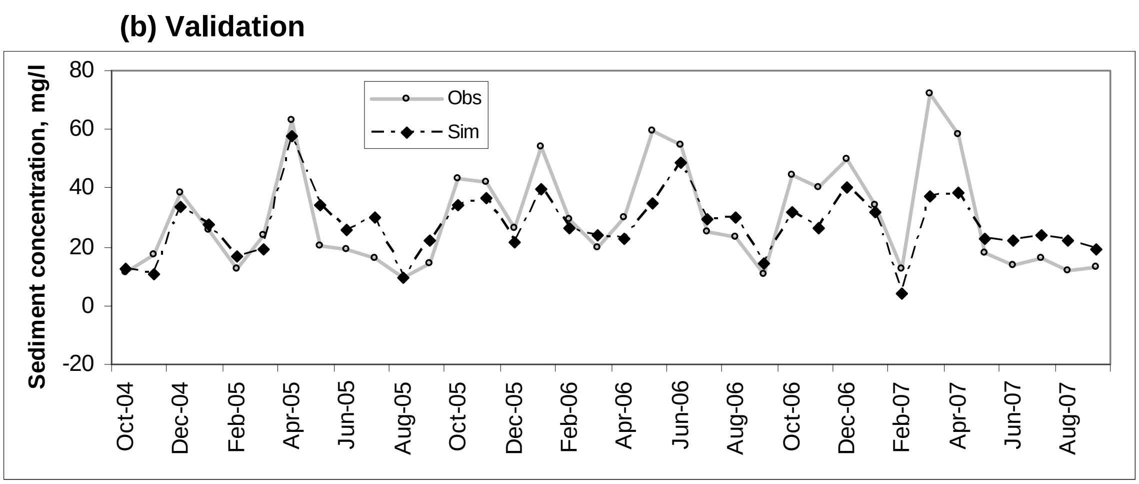


Figure 3-11. Time series plots of SWAT simulated versus observed (measured) for monthly sediment concentrations during (a) calibration and (b) validation periods.

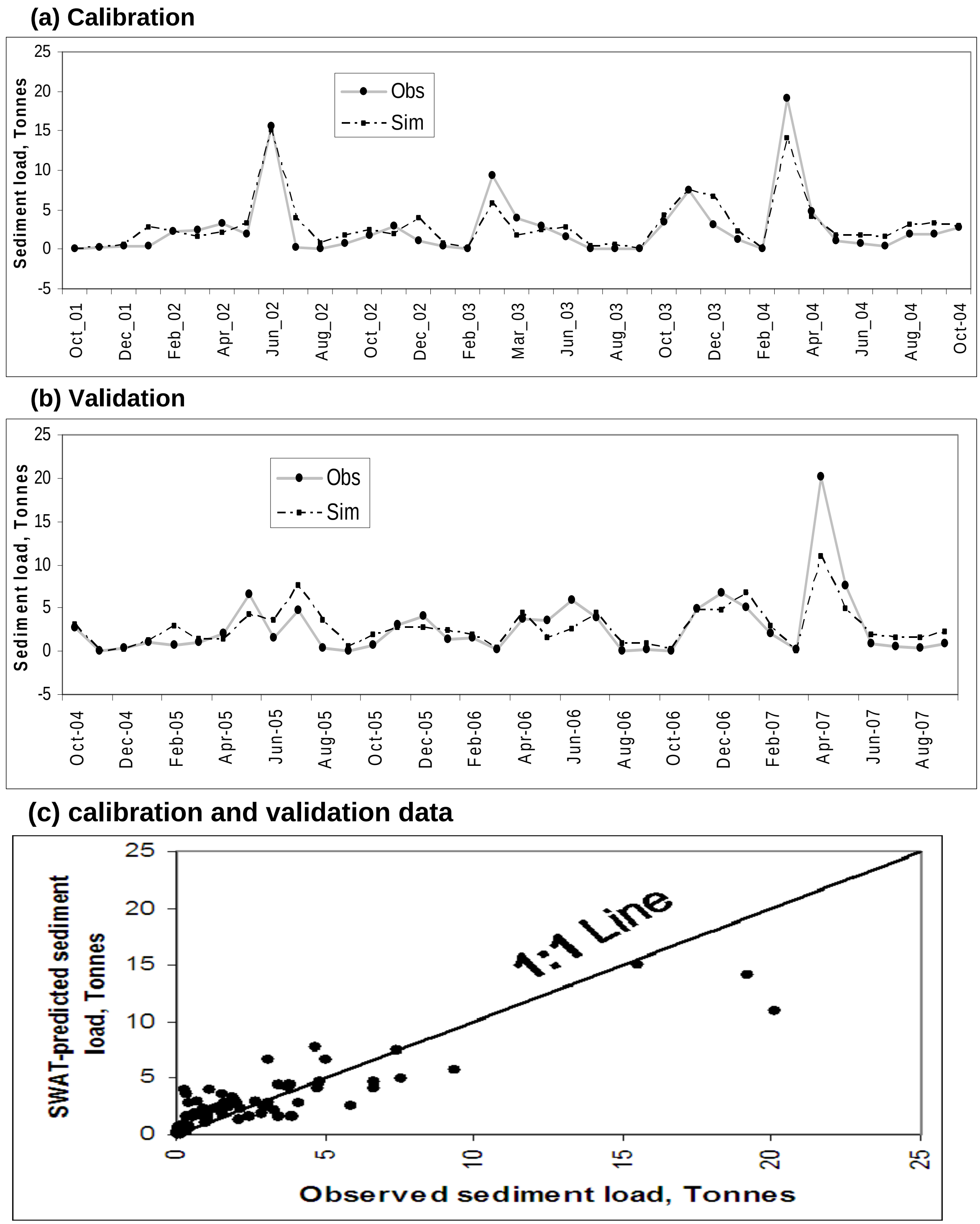


Figure 3-12. Time series plots of SWAT simulated versus observed (measured) for monthly sediment loads during (a) calibration and (b) validation periods; c) scatter plots for data included in calibration validation.

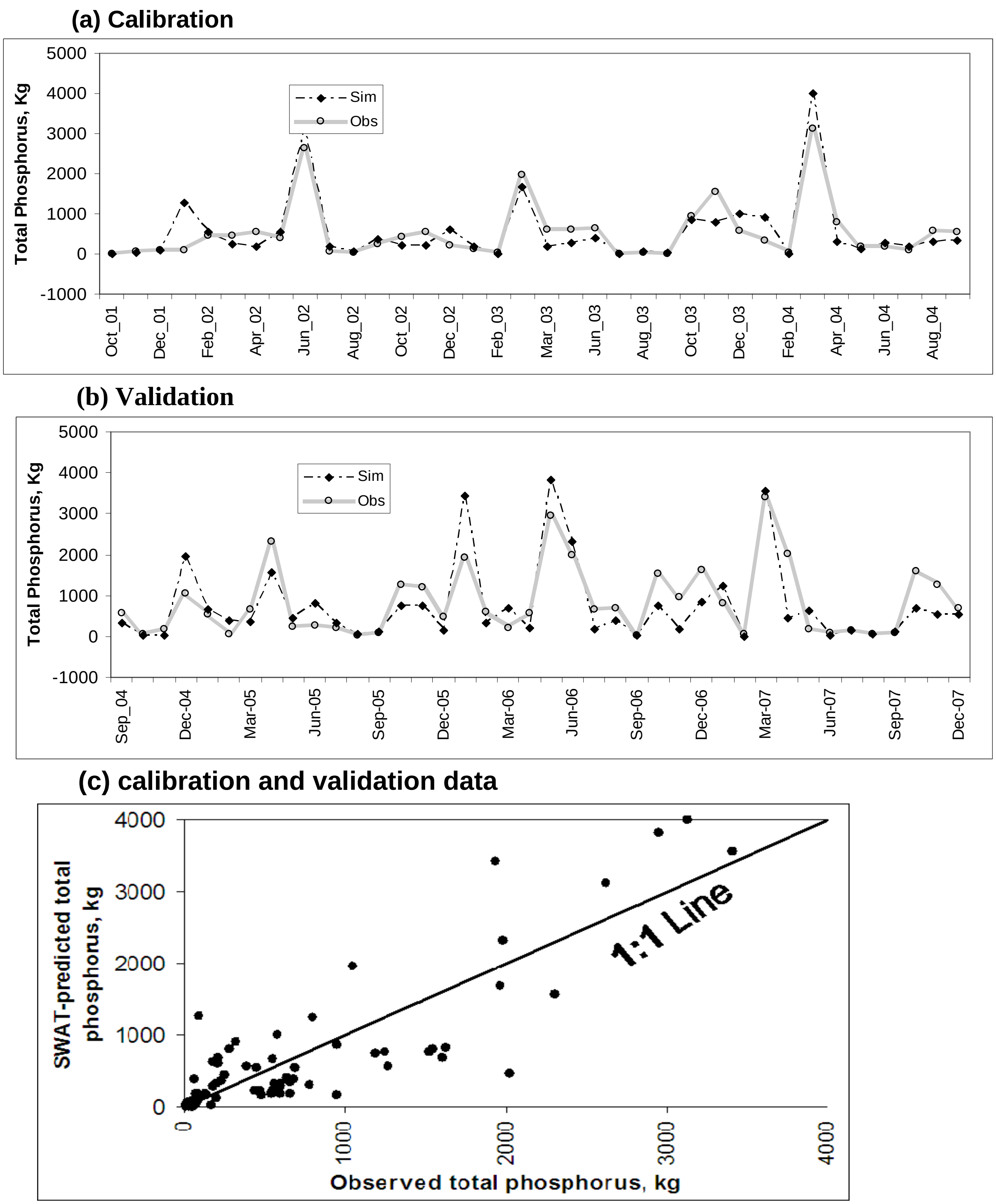
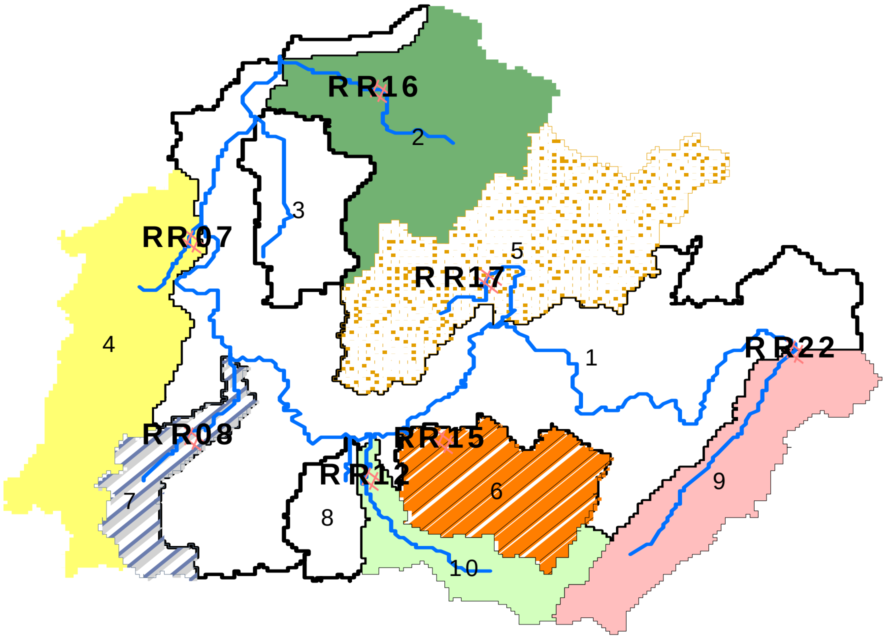


Figure 3-13. Time series plots of SWAT simulated (Sim) versus observed (Obs, measured) for monthly total phosphorus loads during (a) calibration and (b) validation periods; c) scatter plots for data included in calibration validation.

Comparison of SWAT-predicted and Vermont Agency of Natural Resources -ANR synoptic sample of phosphorus data. As discussed previously, SWAT-predicted total phosphorus load was validated at the outlet of the Rock River Watershed using observed data from 12/30/2004 to 12/30/2007. In addition, model prediction of total phosphorus was validated against Vermont Agency of Natural Resources -ANR synoptic sample data. As part of on-going ANR efforts, several grab water samples were collected from Rock River Watershed tributaries during the period April 2008 to April 2009 and were analyzed for their sediment and phosphorus contents. For most of the tributaries, the number of samples collected was 3 in April, 2 in May, 2 in June, 1 in July, 1 in September, and 1 in November. In our analysis, for the months with multiple sample data, a single value of total phosphorus concentration was calculated for each month averaging. This was done because flow-weighted mean concentrations could not be obtained as there was no flow record taken during the sampling. Then, these phosphorus concentrations were compared to the SWAT-predicted monthly values. Comparisons were made only for the months in the year 2008 because weather data were available.

Several sample points matching SWAT-developed subbasin stream networks were selected to perform the overall comparison (Figure 3-14). Figure 3-15 shows these comparisons for the selected tributaries in the Rock River Watershed. Even though quantitative analysis was difficult with the limited amount of data, descriptively, SWAT-predicted total phosphorus concentration seems to have similar overall trend as the sampled concentration data, except for months with lower flow (July and September) where the model consistently predicted lower concentrations than the sampled data.

Overall, the ANR sample data was useful to compare the trend and general magnitudes of SWAT-predicted total phosphorus. However, because of the limited number of ANR samples and the lack of associated measured flow data, comparisons and model validation were limited. Having said that, total phosphorus loads were estimated for the SWAT-delineated sub-basins using the sample concentrations and stream flow predicted by SWAT for each sub-basin. These loads were then compared to the SWAT-predicted total phosphorus loads as shown in Figure 3-16. Based on the graph, there is a general agreement between the predicted total phosphorus loads and the loads estimated from sample concentrations and model-predicted flow.



Subbasin codes		
ANR	SWAT	Area, ha
RR22	9	550.7
RR17	5	967.0
RR16	2	785.5
RR15	6	452.8
RR12	10	303.6
RR08	7	248.7
RR07	4	772.4

Figure 3-14. Vermont Agency of Natural Resources -ANR synoptic sample points and corresponding SWAT-delineated subbasins selected for validating phosphorus predictions.

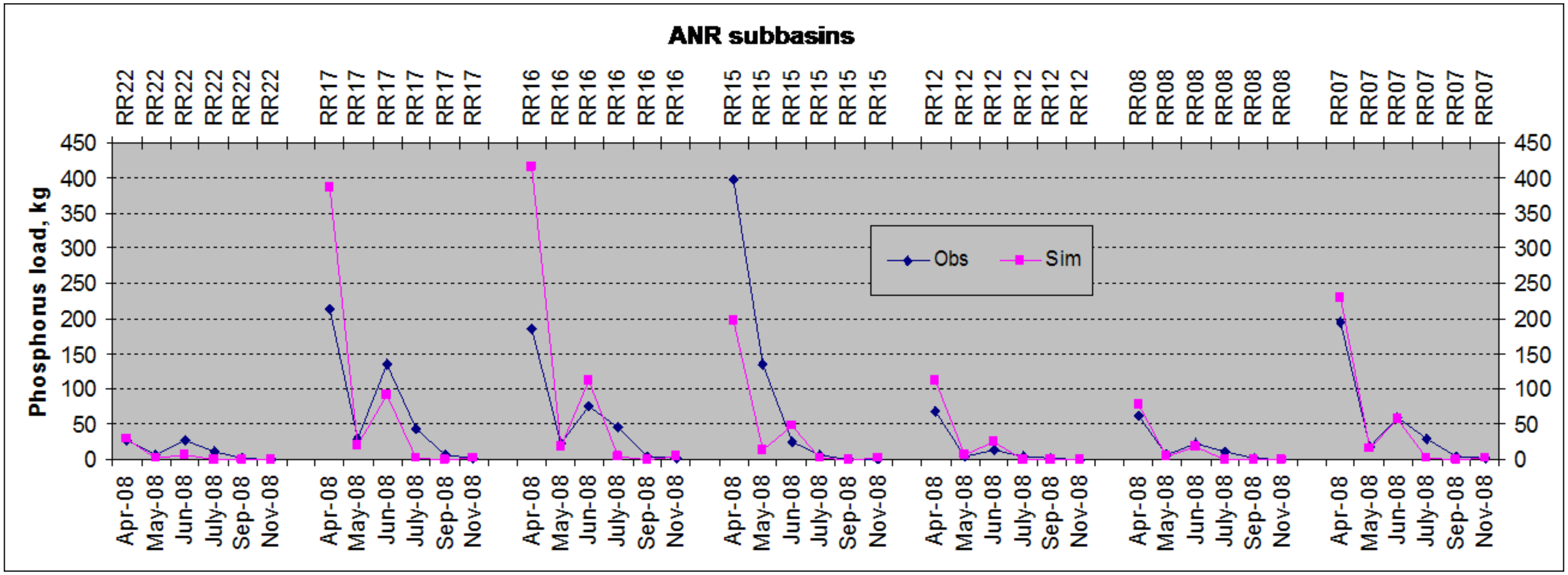


Figure 3-15. SWAT-simulated (Sim) versus the Vermont Agency of Natural Resources -ANR samples (Obs, measured) of total phosphorus concentrations for months of April 2008 through November 2008 in the Tributaries of Rock River Watershed.

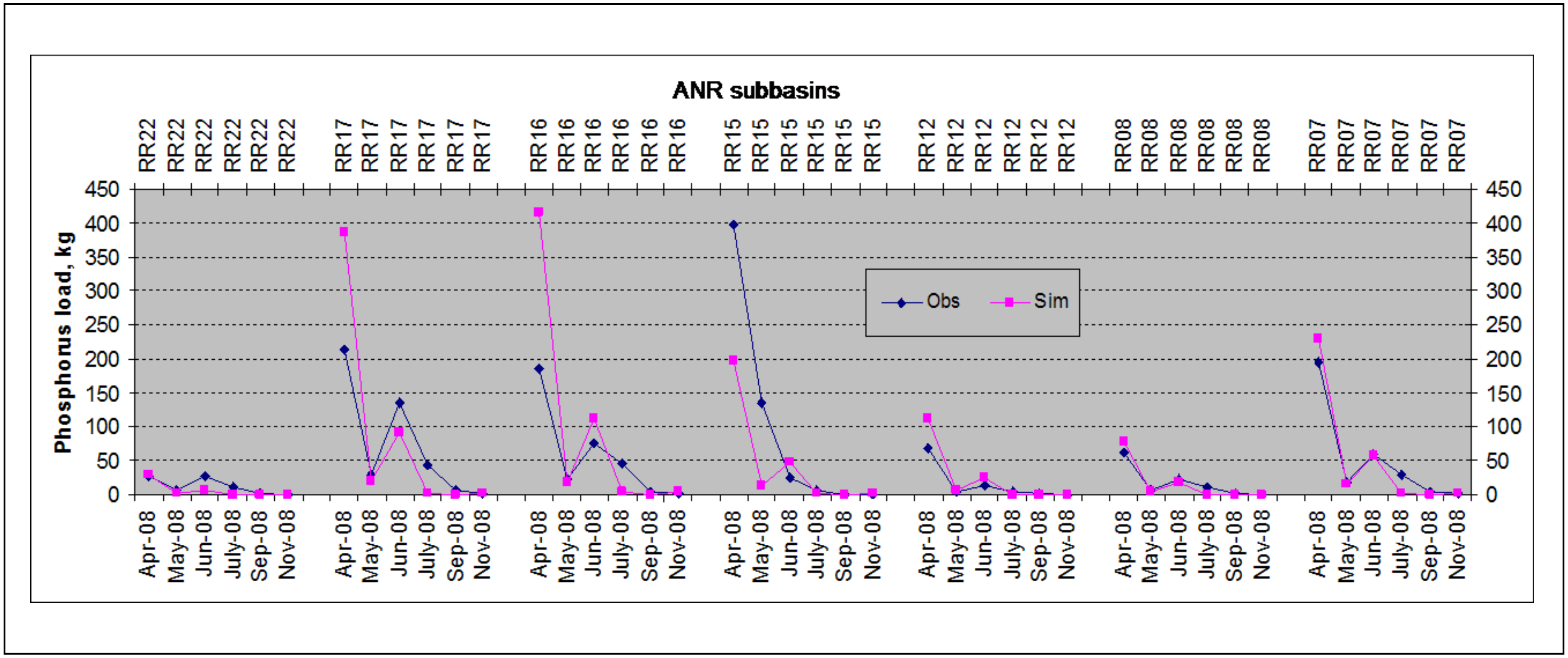


Figure 3-16. SWAT-simulated (Sim) versus the Vermont Agency of Natural Resources -ANR samples (Obs, measured) of total phosphorus loads for months of April 2008 through November 2008 in the Tributaries of Rock River Watershed.

SWAT-predicted Sediment and Total Phosphorus Loads. In this section, SWAT-predicted seven-year average annual total phosphorus and sediment loads in the Rock River Watershed are presented at a watershed and sub-basin levels. Table 3-6 and Figure 3-17 show loads of phosphorus and sediment partitioned by broader landuse type within Rock River Watershed. These data suggest the proportions of pollutant losses from various land uses.

Losses predicted from farmstead area may be low for poorly managed farmsteads. SWAT simulation of animal production areas such as the farmstead requires model input data on phosphorus concentrations by discharge and/or soil phosphorus from barnyard area.

Farmsteads in SWAT are modeled as urban land; in this study, we selected the medium-density urban land use category in SWAT to represent them. Land use characteristics included an impervious area of 38% of the total area, of which 30% was directly connected to stream networks. Runoff was estimated from these areas using urban runoff estimation methods presented in the model description. Regression models were then used to estimate sediment and phosphorus loadings as a function of total storm rainfall, drainage area, and impervious area.

Data on phosphorus concentrations in discharge and soil phosphorus concentrations from each farmstead area in the Rock River Watershed (38 active farmsteads) was not available. Also, manure discharges from barns were not modeled and this also may contribute to prediction underestimates. When known, discharges from barnyard and manure storage areas can be also modeled in SWAT by adding them as a point source input of phosphorus.

Table 3-6. Data showing SWAT-predicted percents of sediment load, and phosphorus loads from various land uses in the Rock River Watershed.

Land uses	Percent (%) Watershed Area	Particulate Phosphorus	Soluble Phosphorus	Total Phosphorus load	Sediment load
Developed(building, road and open space)	5.6%	6.9%	1.8%	6.2%	12.5%
Agricultural crops*	12.7%	27.3%	2.8%	24.1%	32.0%
Rangeland	1.3%	0.0%	0.4%	0.1%	0.0%
Forest	34.3%	0.3%	2.1%	0.6%	0.3%
Water and wetland	0.8%	0.0%	0.4%	0.1%	0.0%
Farmstead**	0.6%	1.5%	1.2%	1.5%	2.2%
Hay	24.8%	1.0%	59.3%	8.5%	0.4%
Corn	17.1%	62.7%	21.4%	57.3%	52.4%
Pasture	2.9%	0.3%	10.6%	1.6%	0.1%

Agricultural crops* include agricultural landuses without CLU specific crop type.

Farmstead** predictions from farmsteads do not include loads in the discharges from barns.

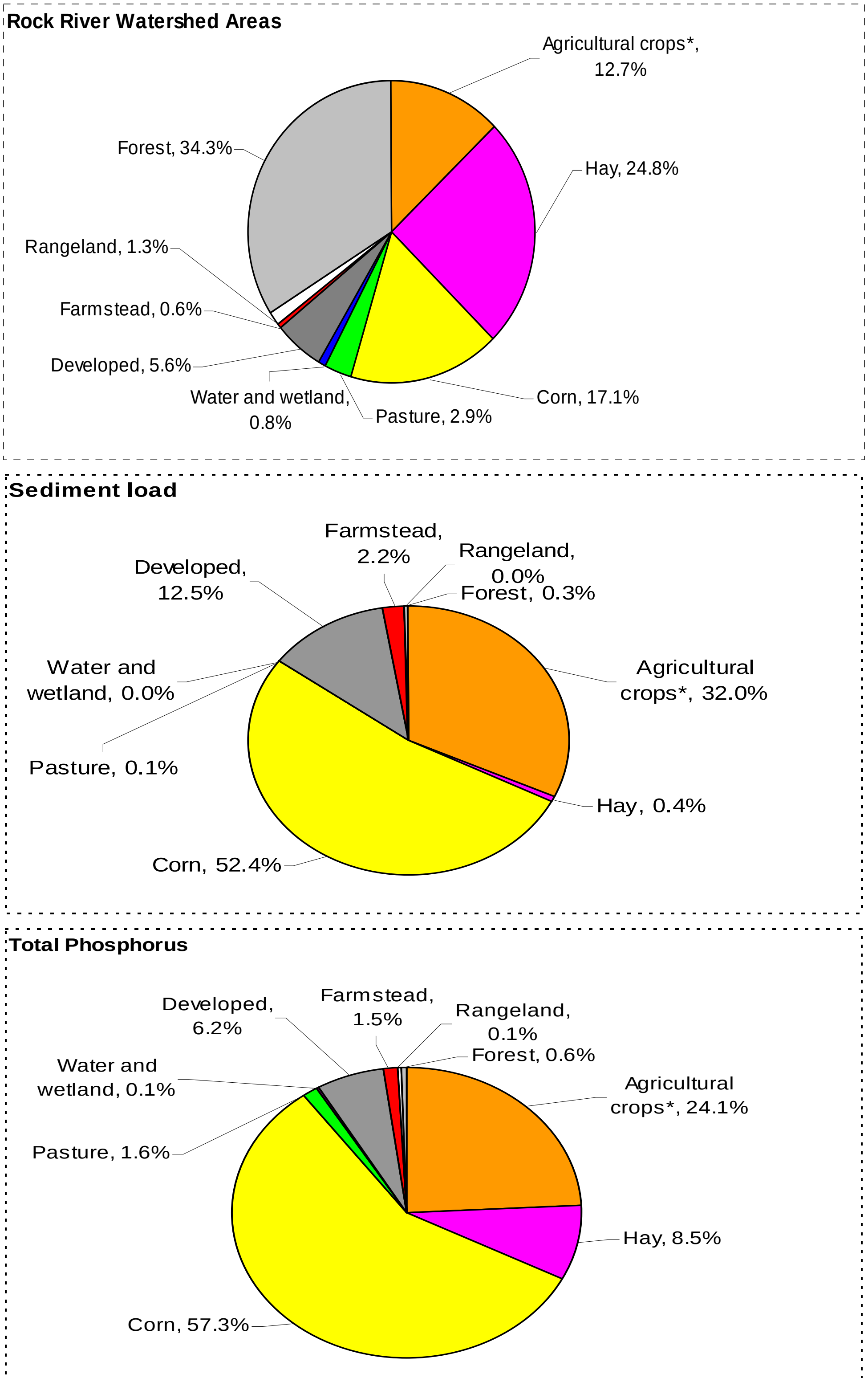


Figure 3-17. Pie Charts showing SWAT-predicted percents of sediment and phosphorus loads from various land uses in the Rock River Watershed during 2001-2008. (Note: Agricultural crops* include agricultural landuses without CLU specific crop type; predictions from farmsteads do not include loads in the discharges from barns).

Table 3-7 shows the specific loads of total phosphorus and sediment for each sub- basin of the Rock River Watershed shown in Figure 3-18. The quantitative data presented in Table 3-7 also shows the proportions of pollutants contributed by different landuse classes in each sub-basin. The amount of total phosphorus load was greater in sub-basins with higher potential transport factors (such as erosion and surface runoff) and phosphorus inputs (as fertilizer and manure). Of the ten sub-basins represented, sub-basin # 9 has the lowest predicted total phosphorus loading rates per hectare, and in contrast, sub-basin # 8 has the highest predicted total phosphorus loading rates. When these contrasting sub-basins were carefully examined, about 82% of the land uses in sub-basin # 9 are forests, while about 90% of the landuse in sub-basin # 8 is agricultural land. More comparisons can be made between sub-basins using the data presented in Table 3-7. A graph in Figure 3-19 also shows sub-basins in the Rock River Watershed ranked from highest to lowest based on the rates of total phosphorus and sediment loads per hectare. Lowest ranks were given for sub-basins with the highest rates of total phosphorus (or sediment) load. Hence, as shown in the Figure 3-19, sub-basin # 8 is ranked 1st, and sub-basin # 9 is ranked 10th (last).

Moreover, from the results (Table 3-7 and Figure 3-19), higher sediment loss is more likely to result in higher total phosphorus loss when associated with higher phosphorus inputs. This is evident in sub-basins # 8, # 6 and # 1. On the other hand, depending on the source of sediment loss (agricultural vs. non agricultural), higher sediment loss rate may not be always directly related to higher total phosphorus losses.   For example, sub-basin # 4 is ranked 5th based on its sediment loss rate, and ranked 6th based on its total phosphorus loss, while sub-basin # 5 is ranked 6th based on its sediment loss rate, but ranked 5th based on its total phosphorus loss. When these two sub-basins are compared, sub-basin # 4 has a higher sediment loss rate than sub-basin # 5, but it has a relatively lower total phosphorus loss rate compared to sub-basin # 5. Developed land (non-agricultural) contributes greater sediment loss in sub-basin # 4 compared to in sub-basin # 5. For sub-basin # 5, the majority of sediment loss was from agricultural crops, which resulted in higher phosphorus loads due to the higher potential for phosphorus inputs as fertilizer and manure. In this study, there was no application of phosphorus fertilizer (lawn fertilizer) in the land use categorized as developed (roads, building, open space around building). These results are expected to be different in urbanized settings in which phosphorus-fertilizer applications on lawns are more likely.

Using the above approach, sub-basins consisting of larger areas with high pollutant losses will have a higher overall loss rate (per area); hence, these sub-basins can be identified as a higher priority for management practices. However, depending on the size of the sub-basin selected for the analysis and the proportion of the land cover that has lower potential loss vs. higher loss, such identification may not necessarily result in accurate identification of areas with the highest risk for phosphorus losses. Within a particular sub-basin, areas with higher phosphorus loss may be masked if they happen to cover a smaller area of the sub-basin relative to other land uses of the sub-basin with lower phosphorus losses, as the effect gets diluted by the larger area. Therefore, careful consideration must be taken to the dilution effect when pursuing a sub-basin level assessment to identify areas with potentially higher phosphorus losses.

The next section presents the results of identification of high risk areas for phosphorus loss based on individual land uses characteristics within the Rock River Watershed.

Table 3-7. Data showing SWAT-predicted magnitudes of sediment and total phosphorus loads and percents of landuses area, sediment load, and total phosphorus load in the sub-basins of the Rock River Watershed.

	Sub-Basin #1			Sub-basin # 2			Sub-basin # 3			Sub-basin # 4			Sub-basin # 5		
	TP, Kg	SS, T	A, ha	TP, Kg	SS, T	A, ha	TP, Kg	SS, T	A, ha	TP, Kg	SS, T	A, ha	TP, Kg	SS, T	A, ha
	4042	19344	2497	866	2879	785	313	1219	344	879	4936	772	1946	4976	967
Land uses	TP, %	SS, %	A, %	TP, %	SS, %	A, %	TP, %	SS, %	A, %	TP, %	SS, %	A, %	TP, %	SS, %	A, %
Developed land	6.7	15.1	5.8	6.6	11.0	10.8	16.3	29.4	7.7	7.9	20.1	5.8	4.4	9.0	4.0
Agricultural crops	24.8	31.2	12.7	25.0	32.5	17.6	24.2	29.5	14.1	22.9	31.5	12.1	18.4	28.5	12.7
Rangeland	0.1	0.0	1.2	0.0	0.0	0.6	0.0	0.0	0.5	0.1	0.0	2.5	0.0	0.0	0.7
Forest	0.5	0.3	33.6	0.3	0.1	18.6	0.5	0.2	27.8	0.6	0.4	44.3	0.2	0.1	22.3
Water and wetland	0.0	0.0	0.6	0.0	0.0	0.2	0.0	0.0	0.0	0.1	0.0	2.0	0.0	0.0	0.4
Farmstead	1,5	2.8	0.6	2.7	3.5	1.1	3.1	4.7	0.6	1.0	1.2	0.3	0.9	1.0	0.4
Hay	7.8	0.4	26.6	10.1	0.3	26.3	18.0	0.5	38.1	7.5	0.4	18.3	9.4	0.4	29.1
Corn	57.4	51.2	16.4	55.4	52.5	24.5	37.7	35.6	10.9	57.0	46.2	10.1	63.0	60.9	23.2
Pasture	1.31	0.1	2.4	0.2	0.0	0.3	0.1	0.0	0.1	2.9	0.1	4.6	3.6	0.1	7.3

	Sub-basin # 6			Sub-basin # 7			Sub-basin # 8			Sub-basin # 9			Sub-basin # 10		
	TP, Kg	SS, T	A, ha	TP, Kg	SS, T	A, ha	TP, Kg	SS, T	A, ha	TP, Kg	SS, T	A, ha	TP, Kg	SS, T	A, ha
	816	3938	453	248	1048	249	432	1916	165	80	242	551	442	2009	304
Landuses	TP, %	SS, %	A, %	TP, %	SS, %	A, %	TP, %	SS, %	A, %	TP, %	SS, %	A, %	TP, %	SS, %	A, %
Developed land	2.4	3.8	3.2	5.7	9.0	5.8	2.3	4.2	3.7	22.2	36.0	1.8	4.3	7.3	3.8
Agricultural crops	22.6	29.0	13.1	54.6	79.9	16.4	15.9	21.1	16.0	25.0	41.2	1.9	30.4	39.5	14.1
Rangeland	0.0	0.0	0.5	0.0	0.0	0.5	0.0	0.0	0.1	1.5	0.7	3.1	0.1	0.0	1.9
Forest	0.4	0.1	36.9	0.4	0.2	18.5	0.0	0.0	5.2	15.4	14.8	82.2	0.5	0.4	39.1
Water and wetland	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.0	2.4	0.1	3.3	0.1	0.0	1.0
Farmstead	0.6	0.5	0.4	2.0	1.5	0.7	1.7	2.8	1.0	0.6	0.6	0.0	1.1	0.9	0.4
Hay	3.7	0.2	14.5	21.0	1.3	42.7	7.6	0.4	41.4	17.9	1.2	5.4	6.1	0.1	19.8
Corn	69.9	66.3	29.8	9.7	7.7	7.2	72.4	71.5	32.6	5.3	5.1	0.3	57.4	51.8	19.8
Pasture	0.3	0.0	1.4	6.6	0.4	8.1	0.0	0.0	0.0	10	0.4	1.9	0.1	0.0	0.2

TP = Total Phosphorus; SS = Sediment; T= tonnes; A= area; developed land includes roads, building, open area around buildings; agricultural crops include crops without specific CLU specific crop types. Note: predictions from farmsteads do not include loads in the discharges from barns.

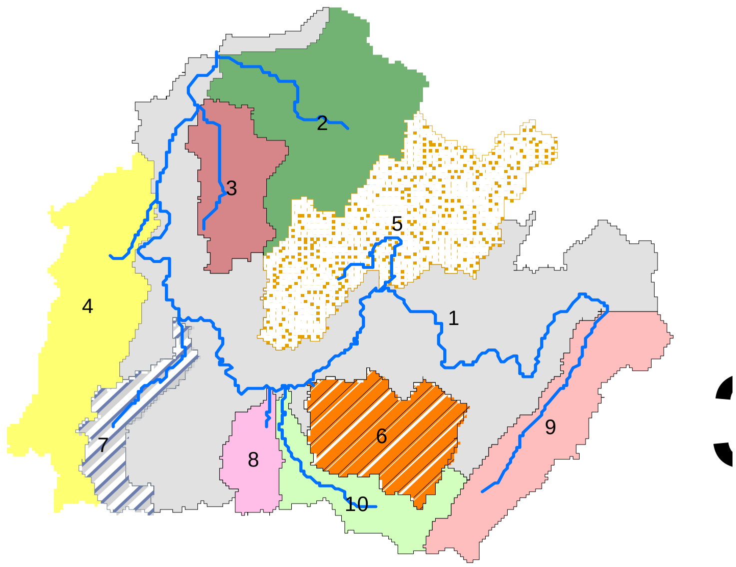


Figure 3-18. Sub-basins of Rock River Watershed represented in the SWAT model.

	Area	TP and SS losses		TP and SS loss Rates		Ranks based on loss rates	
Sub-basins	ha	TP, kg	SS, Tonnes	TP, Kg/ha	SS, T/ha	TP	SS
Sub-basin # 8	165	432	1916	2.62	11.62	1	1
Sub-basin # 6	453	816	3938	1.80	8.70	2	2
Sub-basin # 1	2497	4042	19344	1.62	7.75	3	3
Sub-basin # 10	304	442	2009	1.46	6.62	4	4
Sub-basin # 5	967	1316	5622	1.36	5.81	5	6
Sub-basin # 4	772	879	4936	1.14	6.39	6	5
Sub-basin # 2	785	866	2879	1.10	3.67	7	8
Sub-basin # 7	249	249	1048	1.00	4.21	8	7
Sub-basin # 3	344	313	1219	0.91	3.55	9	9
Sub-basin # 9	551	80	242	0.15	0.44	10	10

Figure 3-19. Sub-basins of Rock River Watershed Ranked according to their SWAT-predicted sediment (SS) and total phosphorus (TP) loss rates. Lower ranks are associated with highest loss rates.

IDENTIFICATION OF CRITICAL SOURCE AREAS OF PHOSPHORUS LOSS

Due to variability in topography, hydrology, soil, and management, all nonpoint phosphorus sources do not contribute equally to water impairment. Some nonpoint sources contribute disproportionally high phosphorus losses than others. Areas within a watershed that contribute disproportionally higher phosphorus loss are often called critical sources areas (CSAs). CSAs for phosphorus loss represent areas with high availability of phosphorus that is at high risk for runoff and erosion transport. Therefore, CSAs for phosphorus loss are affected by the combined effect of phosphorus source and phosphorus transport factors. The phosphorus source factors include the variations in the soil type and field-specific management practices, which in turn include, among others, land use activities, fertilizer and manure applications, tillage, and harvest practices. The modeling set-up in this study watershed was designed to capture all these phosphorus source variations on a field-by-field basis. For instance, the variations due to specific land use and soil type and properties are captured by the model by using detailed land use data and soil data as input in the model. With regard to variations in field-specific management practices, however, due to the limited recorded information, only typical management practices that were specific to crop type are reflected in this study. The use of typical management practices, such as manure application rate, tillage type and timing, harvest timing, and others, are reasonable for our objective in this paper because most farmers plan and schedule farm activities based on specific crop type. Having said that, phosphorus source and phosphorus transport variations within fields of the same crops but differing in the underlying soil and slope properties are captured in the modeling process. These variations are demonstrated in the following section.

SWAT predictions on a HRU level were used to identify high phosphorus loss areas, i.e., CSAs. In this study, an HRU represented an area in a sub-basin that contained a unique combination of landuse, soil type, and slope. For areas with available CLU crop field layer, individual fields were distinctly coded in order to avoid combining side-by-side fields of the same land uses. By distinctly coding individual fields, especially crop fields, amounts of runoff and associated sediment and phosphorus loadings for each crop field can be extracted and, most importantly, the spatial location of the crop fields were maintained for further analysis in determining high phosphorus loss areas. After the completion of the model calibration and validation processes, magnitudes of runoff, sediment, and phosphorus losses from each HRU were analyzed. Analysis of runoff and sediment was an important step in determining areas of high phosphorus losses because phosphorus loss predictions in the model are governed by runoff and sediment transport factors in addition to the phosphorus source factors.

To simplify demonstration of results, maps of sediment and total phosphorus losses that are average for the seven-year period simulations are presented in Figure 3-20. Note that similar maps can be generated for any specific season and year of interest. The maps presented in Figure 3-20 represent different sediment and total phosphorus generations from various HRUs comprised of different landuse, soil, and slope combinations. Areas shaded with darker colors (red) are showing higher sediment and total phosphorus generating areas, while areas with lighter color (white) are showing lower sediment and total phosphorus generating areas. The amount of sediment loss from the landscape affects the amount of phosphorus that is potentially lost into the streams. As shown from the map depicting the spatial variations of total phosphorus loss (Figure 3-20), higher total phosphorus losses are related to areas with higher sediment loss and runoff loss (Figure 3-7) and availability of phosphorus (added as manure and/or fertilizer). These depictions from the SWAT model show the model's ability to generate results that are easily transferable to maps and eventually to the ground where planning takes place. Note that these maps were based on the 2003 CLU crop data layer; therefore, care should be taken when interpreting these results directly on the ground for different crop production years. Due to crop rotations, some fields may be in a different crop year than what is represented in the model. Note also that for farmsteads with potential manure discharges, the phosphorus load results may be under-predicted as loads from manure discharges from barn areas were not represented directly in the model.

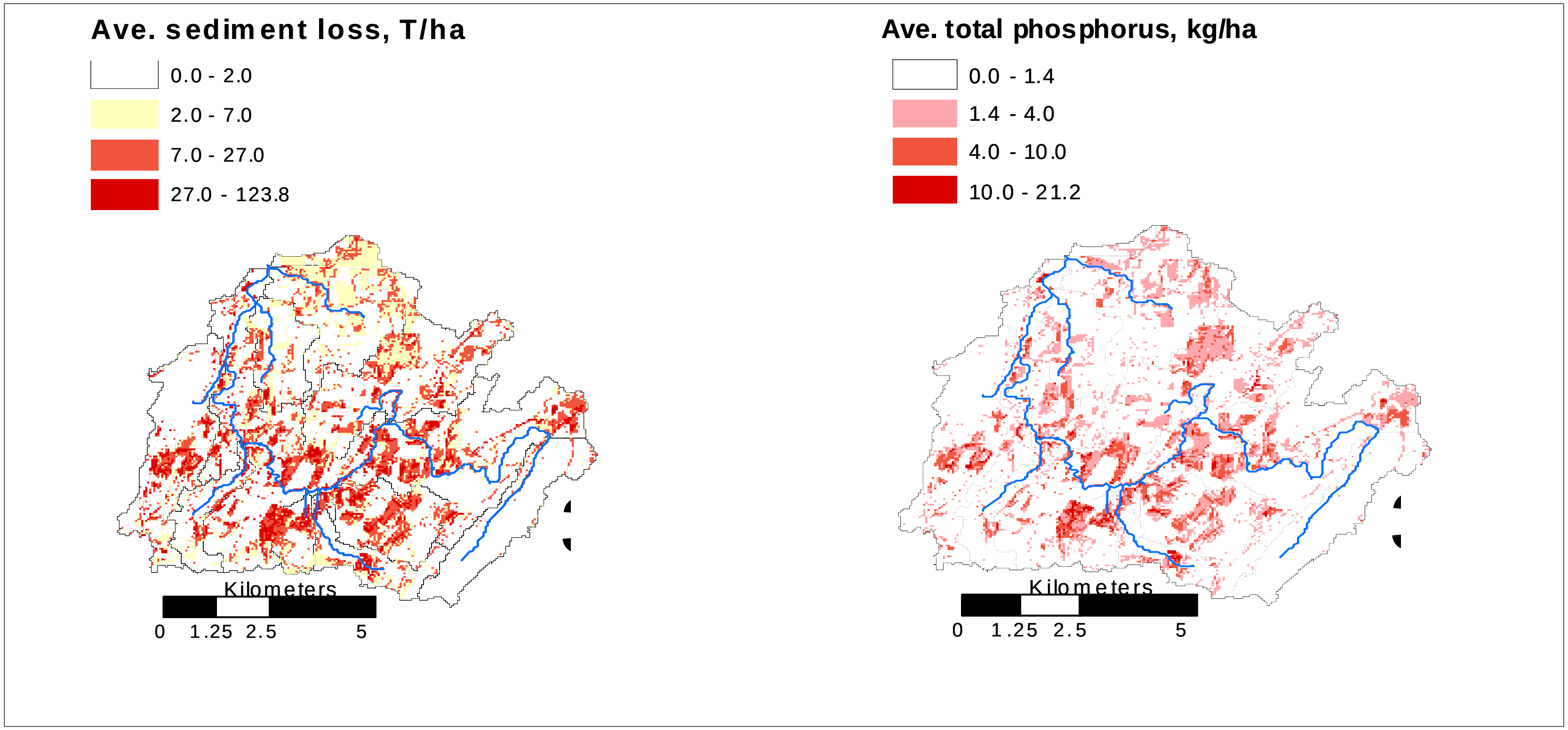


Figure 3-20. Maps showing sediment and total phosphorus loss rates in the Rock River Watershed.

The maps presented in Figure 3-20 shows spatially different ranges of sediment and total phosphorus loss rates. For determining CSAs for the respective pollution levels, it is important to establish threshold values of sediment and phosphorus loads. Threshold loads (rates) are values above which losses can be considered too high, and these values can be established based on literature, load reduction goals (such as, TMDLs), soil productivity goal levels, and/or numerical water quality standards.

In this project, combinations of 5-7 tonnes/ha tolerable soil loss (T) levels for soils in the Rock River Watershed and a 2 kg/ha total phosphorus loss threshold value based on published guidelines for “high” total phosphorus loss (Sharpley and Rekolainen, 1997) were used in selecting a threshold value for total phosphorus loss. We selected a total phosphorus threshold value of 1.4 kg/ha to take into consideration both T levels and high phosphorus loss values. The T is a broadly used criterion in land resource management to control erosion levels so as not to compromise soil productivity. The maps in Figure 3-20 demonstrate the extent of CSAs of phosphorus loss with phosphorus loss rates above the selected threshold value. These kinds of analysis and resulting maps are useful in developing targeted water quality management strategies at the watershed scale.

In addition, HRU were ranked from high to low based on their SWAT-predicted total phosphorus loss rates, and cumulative total phosphorus and sediment loads were plotted along with loss rates in graphs shown in Figure 3-21. The graphs demonstrate the percentages of HRU areas and the amount and rate of total phosphorus and sediment losses. Based on the pre-defined threshold value of 1.4 kg/ha for total phosphorus loss rate, about 24% of the upland watershed area was predicted to produce about 80% of the total phosphorus load. Depending on the availability of resources and a specific water quality goal, a different threshold rate of total phosphorus loss could be selected to target areas with high phosphorus loss risk. Based on the previously selected threshold (1.4 kg/ha of total phosphorus loss), however, the same 24% of the watershed area also attributed to 91% of the total sediment loads. The majority of the areas were predicted to have sediment loss rates greater than 7 tonnes/ha, the highest T value for soils in the study watershed, while some HRUs have sediment loss rates ranging from 4 to 7 tonnes/ha. From the results, some areas with sediment losses rates lower than T produced higher phosphorus losses, indicating that areas with sediment losses less than T level may also be a high risk for phosphorus-related water quality pollution when they have higher phosphorus availability. This type of graph may be a useful guide when allocating resources and targeting areas with high risk for phosphorus and sediment losses. In summary, this kind of analysis provides decision makers excellent information on the quantity and extent of CSAs of phosphorus loss that may need attention and provides a realistic depiction of phosphorus loss areas that potentially have room for improvement.

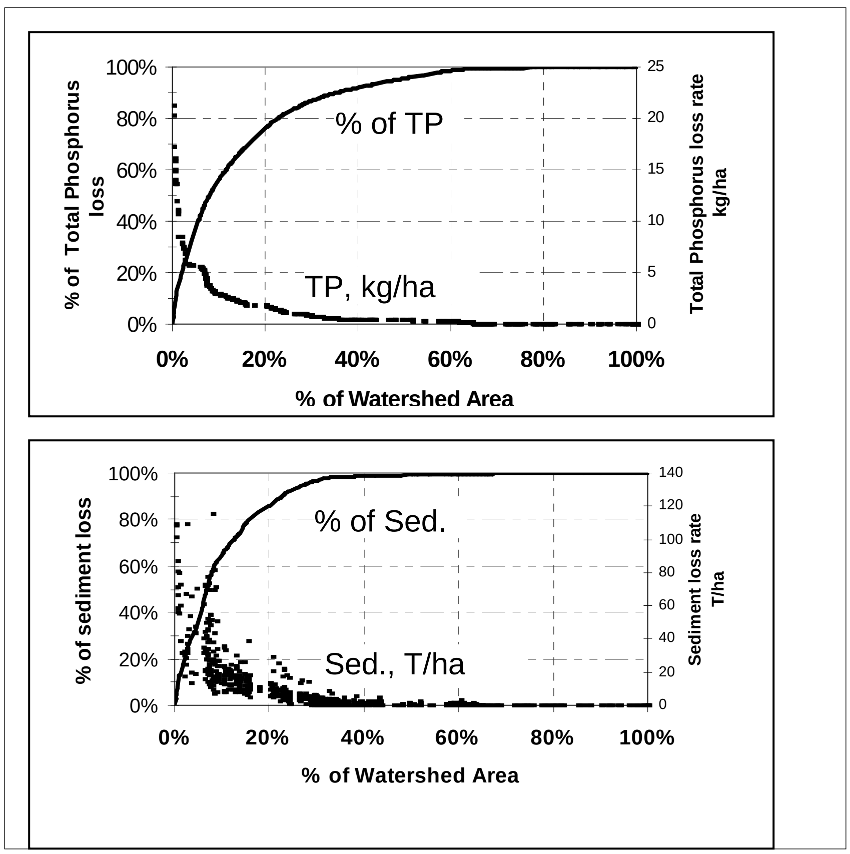


Figure 3-21. SWAT-predicted fraction of watershed rates and loads of total phosphorus (TP) and sediment versus the fraction of Rock River Watershed area.

Characteristics of critical source areas for total phosphorus loss. Details of the 24% of the watershed area identified as producing higher than 1.4 kg/ha of total phosphorus loss are presented in Table 3-8 (also *Appendix A* for all HRUs in the watershed). Of this 24% watershed area, areas of corn, agricultural crops (that were not identified by specific crop type), farmsteads, and developed land (building and roads) constitute 13%, 8%, 0.3% and 3%, respectively. Less ground cover, erosive soil type, steep slopes, and phosphorus availability contributed to these high total sediment and total phosphorus losses. In other words, results demonstrate that corn, other cropland, and urban areas, on higher slopes, are the high-yielding HRUs for phosphorus loss. Note that for farmsteads with potential manure discharges, the phosphorus losses may be under-predicted as loads from manure discharges from barn areas were not represented in the model. As shown from the detailed output for corn (Table 3-8), magnitudes of total phosphorus and sediment loads differ for corn fields managed similarly due to the difference in soil type and slope. The presence of soils of C and D hydrologic groups, and higher slopes makes agricultural fields (such as corn fields) susceptible to runoff, erosion and phosphorus loss, especially in combination with higher availability of phosphorus in fields resulting from applications of manure and phosphorus fertilizer.

Table 3-8 Characteristics of land use area, phosphorus and sediment loss rates in the Rock River Watershed identified as having high total phosphorus loss rates.

		Total phosphorus		Sediment	
Landuse-soil-slope	Area, ha	Loss, Kg	Loss rate, kg/ha	Loss, Tonnes, T	Loss rate T/ha
CSIL_A_>15%	0.3	1.5	4.3	6	18.5
CSIL_A_3-8	9.9	19.7	2.0	75	7.6
CSIL_A_8-15	3.3	14.1	4.3	60	18.4
CSIL_B__>15%	1.3	11.7	8.9	64	48.8
CSIL_B_3-8	32.5	136.8	4.2	621	19.1
CSIL_B_8-15	11.1	101.7	9.2	570	51.5
CSIL_C__>15%	9.6	95.6	10.0	441	46.0
CSIL_C_3-8	227.0	973.4	4.3	3892	17.1
CSIL_C_8-15	65.6	574.2	8.8	2500	38.1
CSIL_D_0-3	338.2	613.5	1.8	2288	6.8
CSIL_D__>15%	3.2	42.4	13.1	261	80.7
CSIL_D_3-8	189.7	1056.6	5.6	4891	25.8
CSIL_D_8-15	29.4	326.8	11.1	1877	63.9
FRMS_A_8-15	0.2	0.3	1.5	2	9.0
FRMS_C__>15%	0.8	1.9	2.2	12	13.8
FRMS_C_3-8	11.6	20.5	1.8	129	11.1
FRMS_C_8-15	4.6	11.5	2.5	84	18.2
FRMS_D__>15%	0.7	1.7	2.6	26	40.1
FRMS_D_3-8	3.3	7.5	2.3	73	22.4
FRMS_D_8-15	2.0	5.6	2.8	82	41.9
AGRI_A__>15%	2.5	5.8	2.3	38	15.0
AGRI_A_8-15	6.9	15.0	2.2	97	13.9
AGRI_B__>15%	4.1	11.1	2.7	139	34.0
AGRI_B_8-15	8.6	17.2	2.0	163	18.9
AGRI_C__>15%	46.8	189.3	4.2	1698	33.3
AGRI_C_3-8	180.7	265.7	1.5	1430	7.7
AGRI_C_8-15	121.1	381.6	3.2	2824	22.6
AGRI_D__>15%	20.1	54.4	2.3	634	28.7
AGRI_D_3-8	120.3	260.7	2.2	1575	11.7
AGRI_D_8-15	61.2	200.0	3.4	1922	26.6
URLD_A_8-15	1.2	2.2	1.8	18	14.9
URLD_B__>15%	2.6	8.5	3.2	157	59.8
URLD_B_8-15	4.1	7.1	1.7	90	22.1
URLD_C__>15%	19.7	64.3	3.3	737	37.4
URLD_C_3-8	71.5	114.0	1.6	753	10.5
URLD_C_8-15	44.9	127.9	2.9	1233	27.5
URLD_D__>15%	11.4	28.4	2.5	417	36.5
URLD_D_3-8	34.0	87.8	2.6	593	17.5
URLD_D_8-15	19.2	63.1	3.3	748	38.9

CSIL = corn; AGRI = Agricultural land use, FRMS = farmstead; URLD = developed; Note that CSIL_A__>15% = land use (corn) _soil hydrologic group (A)_ slope (>15%).

Using the information above, management strategies such as cover crop and minimum tillage can be targeted to corn fields with higher phosphorus loss rates instead of implementing these management strategies on all corn fields. Though not explicitly drawn from the modeling results, in addition to the high phosphorus loss rate, corn fields can be further selected based on their closeness to streams. Corn fields with higher phosphorus loss rates that are close to streams are likely to have a higher potential and immediate threat of phosphorus loss. Thus, they are recommended as a very high priority for management implementation.

Overall, this study shows varying runoff, sediment and phosphorus losses from fields of the same landuse, emphasizing the importance of using a science-based systematic methodology, such as this SWAT model, in identifying the areas with higher risks for pollution. Such model based identification of potentially high phosphorus loss areas will help in exploring and planning cost-effective phosphorus management strategies with the highest potential for phosphorus loss reductions in the Rock River Watershed. In addition, insights and findings about the characteristics of CSAs identified in this study watershed can be employed in other similar settings watersheds in the Lake Champlain Basin.

IV-EFFECTIVENESS OF AGRICULTURAL MANAGEMENT PRACTICES

Assessment of Management Practice Effectiveness

Agricultural management practices are increasingly used to reduce nonpoint source water pollution resulting from agricultural land uses and activities. In this study, a model-based approach was used to investigate the effects of management practice alternatives that have a potential to reduce phosphorus loadings. The SWAT model was used to assess individual management practice effectiveness in reducing phosphors loads. Potential management practices assessed were developed based on information acquired in several stakeholder meetings, discussions with extension personnel, reviews of related USDA-NRCS publications, and literature reviews of potential management practices relevant to our study watershed. Management practices assessed are presented below.

Management Practices and Model Representations

Minimum tillage. A minimum tillage management practice was imposed on all corn fields. Because all soils in the Rock River Watershed may not be suitable for no-till practice due to cold weather and heavy textured soils, the minimum tillage practice was assumed to include in-row tillage systems such as zone- and strip-till that disturb less soil surface. The benefits of minimum tillage (no-till) include reduction of soil erosion, improvement of soil physical structure, conservation soil water, and restoration of organic matter (Lal et al., 2004; Wright and Hons, 2004). Appropriate tillage equipment was selected from tillage input files to represent this practice in the SWAT model.

Cover crops. This practice involved planting winter small grains on all corn fields as a cover crop. Benefits of cover crops include reduced transport of sediment from fields (Mutchler and McDowell, 1990; Dabney et al., 2001) and increased nutrient use efficiencies (Shipley et al., 1992; Reicosky and Forcella 1998). Cover crop was simulated by planting winter small grains following corn harvest in the agricultural management input files.

Erosion control measures. Erosion control practices may include methods such as contour farming, contour strip cropping, and terraces, which are implemented to control erosion and to meet soil loss tolerance levels. This practice was represented in the model by adjusting appropriate model parameters, including the practice "P" factor in the MUSLE.

Filter Strips. This strategy applies filter strips of 7.6 m (25 ft) on both sides of streams in the Rock River Watershed (Figure 4-1). Filter strips, also known as, vegetative filter or buffer strips, are areas between streams and other land uses (cropland, grazing land, and others) that are planted with grass vegetation to filter sediments and nutrient from runoff water. Installation of filter strips was simulated by adding 7.6 m (25 ft) edge-of-field filter strips in all sub-basins within Rock River Watershed. Because no specific information was available on existing filter strips, the baseline model simulations may not directly account for any existing filter strips. Therefore, this strategy may double count benefits for fields that have already installed filter strips. Also, it is important to note that the implementation of filter strip should follow implementation of land based management practices.

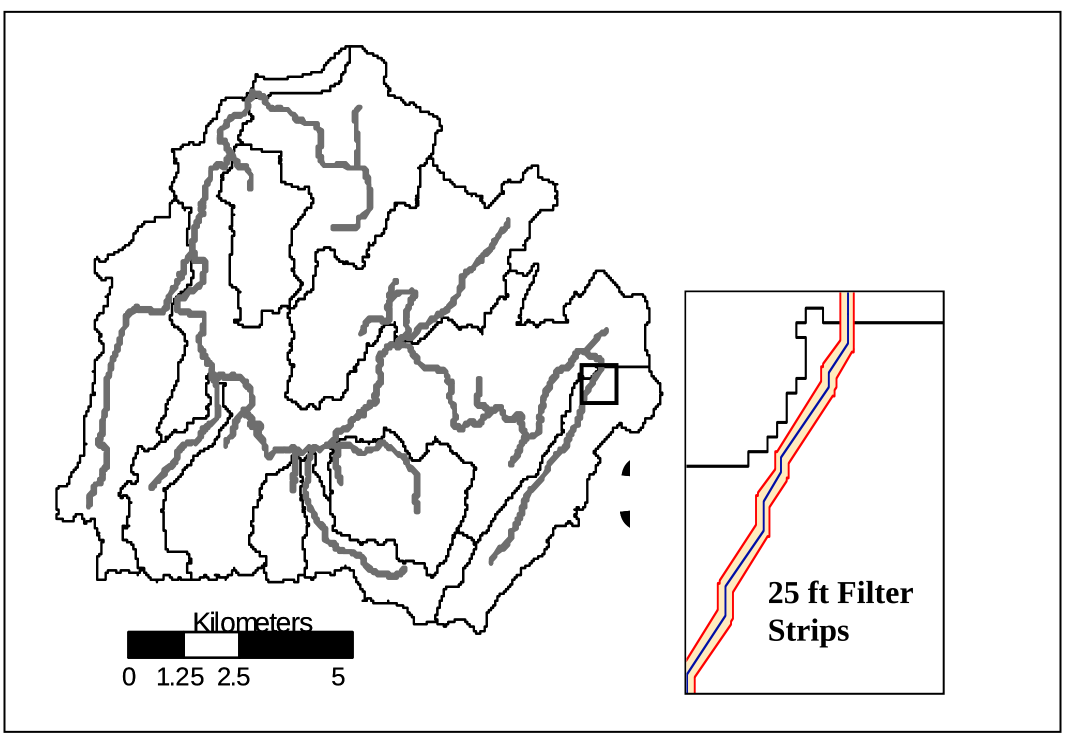


Figure 4-1. Rock River Watershed streams considered for Filter Strips implementation.

Reduced phosphorus manure application (dietary phosphorus reduction). This strategy involves application of manure with reduced phosphorus content. Manure phosphorus can be reduced by modifying dairy cow diets and minimizing overfeeding of phosphorus nutrients. This strategy was implemented on a farm-by farm basis (as previously discussed in Section II). Currently, there are about 37 dairy farms in Rock River Watershed. Dietary phosphorus level of all farms in the Rock River Watershed was not assessed due to limitations of time and data. However, data gathered from three farms in the study watershed and in Franklin County showed that current dietary phosphorus levels of farms in the study region ranged between 0.41% and 0.50%. Compared to the 0.38% NRC-recommended dietary phosphorus level for high-producing dairy cows, currently these farms are overfeeding phosphorus by an average of 15%. Implementation of this strategy at a watershed scale assumed that all cows in the Rock River watershed would receive dietary phosphorus reduction of 15% in order to match the NRC recommendations for dairy cattle (NRC, 2001). The assumed 15% average reduction may not be an exact representation of all farms; however, this value is used in the modeling to get a general perspective on the effectiveness of this strategy.

Manure phosphorus used in the baseline condition was reduced to reflect dietary phosphorus reductions. In the SWAT representation of this strategy, manure phosphorus concentration was the only environmental input parameter that was varied. The total mass of manure produced, amount applied to the crops, amount deposited by the grazing cows, and dates of application were kept the same as in the baseline representation. A similar procedure applied to the SWAT model was also used by Santhi et al. (2001) and Ghebremichael et al. (2008) to simulate the effect of dairy-related best management practices that involve phosphorus reduction in dairy feed.

Improved forage production. Similar to the pervious management practice, this strategy is a farm-level management strategy aimed at increasing the yield of forage produced within the study watershed for utilization in animal diets. In reality, increasing forage productivity can be achieved by improved forage management and timely harvesting, and pasture utilization. The objective for increasing forage productivity was to decrease the farm's dependence on purchased feeds in dairy production, and this strategy enhances the uptake of phosphorus by the plants and helps in recycling of soil phosphorus. Thus, in the long-term, soil phosphorus build-up on agricultural fields could be reduced by plant uptake, while reducing phosphorus imbalances of farms.

Based on farm-specific observation and assessments, an average 25% increase in grass yield is an attainable goal for this area when production and harvesting strategies are intensively managed to increase both yield and quality of grass forage. Intensive management of forage to increase forage yield and quality mainly involves improved management by matching nitrogen fertilizer to plant need, appropriate harvest timing and increased harvest times. Because additional nitrogen may be required to boost grass-forage productivity, careful consideration must be also taken in matching nitrogen availability to crop needs in order to control nitrogen losses and increase nitrogen use efficiency for forage production. Increased yield for the entire grass area of 1700 ha in the Rock River Watershed was assumed in order to assess the potential impacts of this strategy on soil phosphorus and plant uptake. In the SWAT model, a 25% increase in grass yield (0.7 ton/acre) was achieved by changing appropriate model parameters related to forage management and harvesting.

Critical Source Areas management strategies- CSA BMP. This includes a combination of two set of management strategies **CSA BMP1** and **CSA BMP2** implemented by focusing on the CSAs of phosphorus loss. The **CSA BMP1** strategy combines cover crops on corn fields identified as CSAs for phosphorus loss in section III (also shown in Table 3-8) and filter strips applied only on the main stem of the Rock River (within Sub-basin # 1 of Figure 3-18). The **CSA BMP2** strategy expands **CSA BMP1** to include and erosion control measures on agricultural crop fields with slopes greater than 8% also identified as CSAs for phosphorus loss in section III (also shown in Table 3-8). The **CSA BMP2** strategy was applied on 20% of the 24% areas identified as CSAs for phosphorus losses which are in crop production and have slopes greater than 8%. Both the **CSA BMP1** and **CSA BMP2** strategies attempt to achieve higher phosphorus loss reduction by focusing management strategies on areas where they are needed most, CSAs for phosphorus loss. Such effort is especially important when allocating limited resources to achieve a maximum phosphorus loss reduction.

Management Practices Effectiveness

The impacts of management practices were evaluated by predicting average annual phosphorus loss reductions resulting from implementation of these practices during the period of 2001-2008 (sediment was also included when possible). SWAT-predictions that were calibrated and validated previously were used as a baseline condition in determining relative change in losses resulting from implementing different management practices. Management practice effectiveness was determined as the percentage by which phosphorus is reduced, and was calculated by subtracting baseline losses from post-implementation losses (from individual practices) and dividing these by the baseline losses. Therefore, negative effectiveness values indicate an increase in the amount of loss as a result of the implementation of a practice, and vise versa. To assess the potential for each management practice to reduce phosphorus losses, individual practices were applied on the appropriate areas at a 100% implementation rate. Management practices effectiveness assessed are presented in Table 4-1. As shown in the Table 4-1, the analysis of management practice effects was done at two-scales; for implementation area alone and at the watershed scale.

Table 4-1. Management practices effectiveness at scales of implementation area and Rock River Watershed.

Management Practices	BMP efficiencies at the area of implementation

	PP	Soluble P	TP	Sediment
Minimum tillage to corn fields (17% watershed area)	21%	-26%	18%	14%
Cover crops to corn fields (17% watershed area)	50%	8%	48%	51%
Erosion control measures to agricultural crops (59% watershed area)	19%	13%	18%	8%
Reduced P manure application (Dietary Phosphorus reduction)	2%	26%	6%	0%
Improving farm-produced forage production	8%	1%	7%	6%

	BMP efficiencies at Watershed level			
	PP	Soluble P	TP	Sediment
Minimum tillage to corn fields (17% watershed area)	13%	-6%	11%	8%
Cover crops to corn fields (17% watershed area)	31%	2%	27%	27%
Erosion control measures to Agricultural crops (59% watershed area	17%	11%	16%	7%
Filter Strips on major streams (Figure 4-1)	40%	20%	38%	40%
Reduced P manure application (Dietary Phosphorus reduction)	2%	25%	5%	0%
Improving farm-produced forage production	0.1%	4%	1%	0%
CSAs BMP1 =cover crops to corn fields (13% watershed area) & filter strips on selected stream	39%	26%	38%	33%
CSAs BMP2 =cover crops to corn fields (13% watershed area) , erosion control measures to agricultural fields with slopes greater than 8%, & filter strips on selected stream	50%	28%	48%	42%

PP = particulate phosphorus, TP = total phosphorus.

Implementing a minimum tillage on corn fields controlled 21% of the particulate phosphorus loss from the fields used for corn silage production, but it increased soluble phosphorus losses slightly. This is in agreement with studies which report that no-till practices that conserve soil can exacerbate losses of soluble phosphorus in surface runoff relative to conventional tillage (Mueller et al., 1984; Sharpley and Smith, 1994). Overall, this practice decreased the total phosphorus loss by 18% from corn fields, resulting in 11% less total phosphorus lost from the watershed. Generally if the soil and its topography are suited, minimum tillage can reduce soil loss compared to a conventional tillage system. However, poorly drained and compacted soils, which are the majority in the Rock River Watershed, may be limiting factors in applying no till or reduced tillage options.

On the other hand, our results indicate that planting winter cover crops as a management practice to corn fields has great potential for reducing erosion and phosphorus losses. The reductions of total phosphorus loss were 48% at field scale and 27% at the watershed scale, when applied to all corn fields, accounting for about 17% of the watershed area. Also, erosion control measures including contour plowing and contour strip cropping have positive benefits in reducing total phosphorus loss by reducing erosion losses. The erosion control measures had a lower efficiency compared to cover crops. They are more effective in areas where slopes are steep and long; in the Rock Rive Watershed, the majority of crop fields have lower slopes. In fact about 64% of the watershed area falls in the 0-8% slope range. These erosion control measures are expected to have a higher efficiency than predicted in this study when implemented only in appropriate areas with higher slopes.

Total phosphorus reduction was greatest when filter strips were implemented. The reduction in total phosphorus at the watershed scale was 38%. This strategy assumed a 100% implementation rate of edge-of-field filter strips.

The two farm-level management strategies assessed, reduced-phosphorus manure application and increased forage yield, resulted in a minimal effect on total phosphorus loss compared to the management practices previously assessed. However, the benefits of these two management strategy at the farm scale are significant because phosphorus is addressed at its source and these practices may have a potential to benefit farms economically as farms may buy less feed with this strategy. Because the concentration of phosphorus in the manure is reduced, SWAT predicts a 24% reduction in the amounts of phosphorus transferred to the soils, thus a reduced potenital of phosphorus accumulation in the soils. Most importantly, this strategy has the potentail to reduce the amount of phoshorus in manure that needs to be managed in the first place.

For the second farm-level managemnt strategy, when forage yield was increased, SWAT predicted an increased uptake of phosphorus by higher-yielding forages, resulting in 15% increase in utilization of soil phosphorus. Evaluations of these farm strategies at a watershed level were provided to illustrate the importance of integrating farm-level strategies (the smallest management unit) into a watershed based planning approach. Eventually, any management changes will be done on a farm-by-farm basis. Hence, potential management practices selected at a watershed level also need to consider the practicality on farms and the impacts of these changes on the profitability the farms.

Other management practices of interest to the Rock River Watershed were nutrient management plans and barnyard management. These two management practices could not be represented in the SWAT model, therefore we used a Best Management Practice Tool-BMP tool (Gitau et. al., 2005) to estimate the effectiveness of these management practices.
A nutrient management plan, as included in the BMP tool, includes various practices including crop rotation and managing the rate, timing, and placement of fertilizers and manure to maximize nutrient recycling while minimizing loss to the environment. The barnyard management strategies are practices applied in areas of livestock concentrations and eliminate the mixing of rainfall or runoff water and wastes from the barnyards or feedlots. These practices include roof runoff management, diversion, proper waster storage facilities and other practices.

Data obtained from the BMP tool indicate average efficiency values for a set of practices grouped under nutrient management plan to be 46%, 26%, 47% for reducing particulate, soluble and total phosphorus losses, respectively. Similarly, barn management practices show efficiencies of 41%, 26%, 55% for particulate, soluble and total phosphorus losses, respectively using the BMP tool.

Lastly, a management strategy targeted to areas that are identified as CSAs for phosphorus loss was assessed using the SWAT model. By implementing the CSA BMP1, a combination of cover crops on corn fields identified as CSAs for phosphorus loss, and filter strips on the main stream of Rock River, a 38% reduction efficiency for total phosphorus loss was predicted at the watershed scale. This strategy focused only on corn fields accounting for 13% of the watershed area and on the main stem of the Rock River. Moreover, when CSA BMP2 was applied (cover crops to corn fields, erosion control measures to agricultural fields with slopes greater than 8%, and filter strips on selected streams), a 48% reduction in total phosphorus loss was estimated. This CSA BMP2 strategy treated >20% of the 24% of the watershed identified as CSAs for phosphorus losses (Section III; Table 3-8) that are in crop production. Overall, higher total phosphorus reduction efficiencies were estimated when management strategies were focused on areas that are identified to generate higher rates of phosphorus loss.

Assessing Potentials of Management Practices toward Meeting Phosphorus Reduction Goals

In the previous section, the effectiveness of management practices was evaluated and presented. This section extends the analysis to include the potential of these management practices to meet a phosphorus reduction goal set at the watershed level. It is designed to illustrate an approach that could be applied to evaluating progress towards achieving loadings reduction targets or water quality goals for phosphorus in Lake Champlain. The same approach may be used to evaluate other management practices not included in this study and/or combinations of management practices.

Because no phosphorus reduction goal is currently set specifically for the Rock River Watershed, a 52% reduction goal for total phosphorus loading to Missisquoi Bay, calculated from the "*State of the Lake*" report (Lake Champlain Basin Program, 2008) specified as the reduction needed from the 2000-2006 mean load to reach the TMDL target load, was selected as the reduction goal for the Rock River Watershed. Then various management practices were evaluated for their potential to help achieve a 52% reduction in total phosphorus at the watershed-level. This reduction goal can be altered to match specific reduction and water quality objectives if they are established.

To do the analysis, Figures 4-2, 4-3, 4-4, and 4-5 were developed using similar methods illustrated in Section III of Figure 3-21, that is, the HRU areas within the watershed were ranked from high to low based on their SWAT-predicted total phosphorus loss rates, and cumulative total phosphorus loads and loss rates were plotted against percent of cumulative area treated. Similar graphs could be made for any scenario. By overlapping the graph for a particular management strategy with the baseline predictions, the relative change in phosphorus loss rates and total phosphorus losses achieved by implementing management strategies can be determined. In addition, predefined reduction goals for phosphorus loading can be included to illustrate the potential of the management measures to meet the phosphorus reduction goal for the watershed. The 52% reduction goal selected in this analysis is represented in all graphs shown in Figures 4-2, 4-3, 4-4, and 4-5.

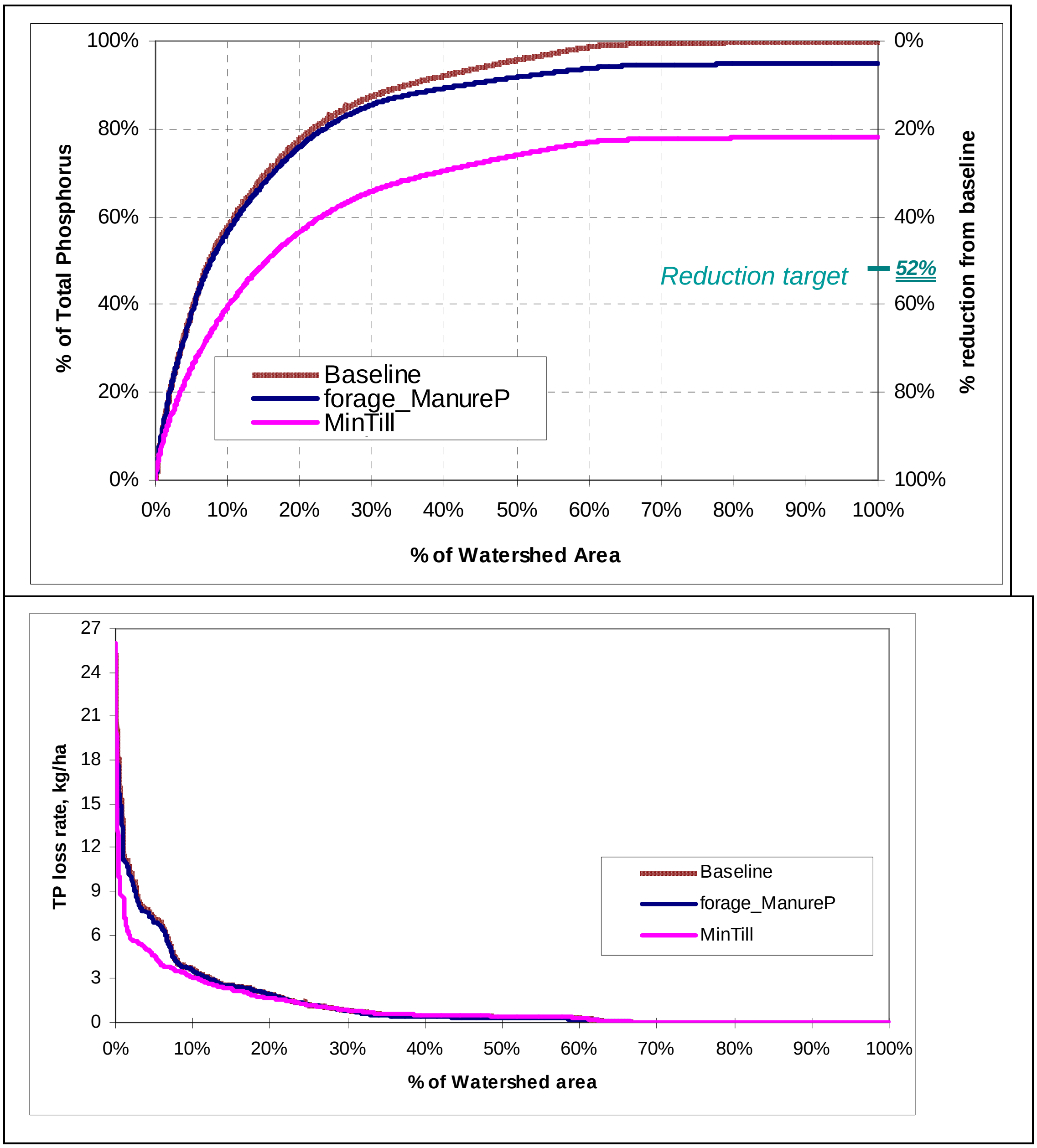


Figure 4-2. Potential reductions in phosphorus load that could be achieved using forage and manure management (includes management practice of increasing forage yield and application of reduced phosphorus manure achieved by decreasing cow dietary

phosphorus) and minimum tillage practices in the Rock River Watershed. A 52% reduction is shown as a potential phosphorus reduction goal from baseline.

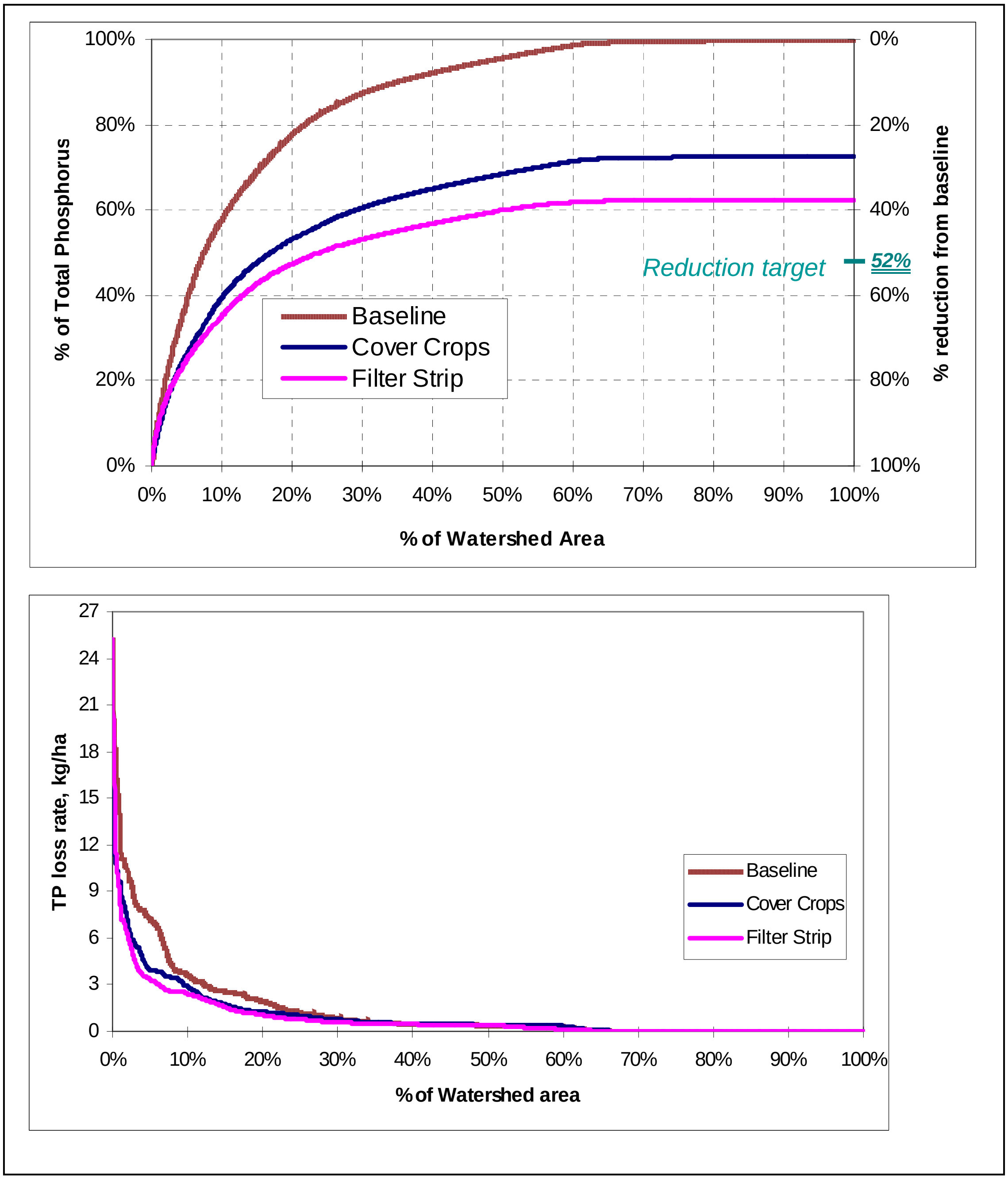


Figure 4-3. Potential reductions in phosphorus load that could be achieved using cover crop and filter strip practices in the Rock River Watershed. A 52% reduction is shown as a potential phosphorus reduction goal from baseline.

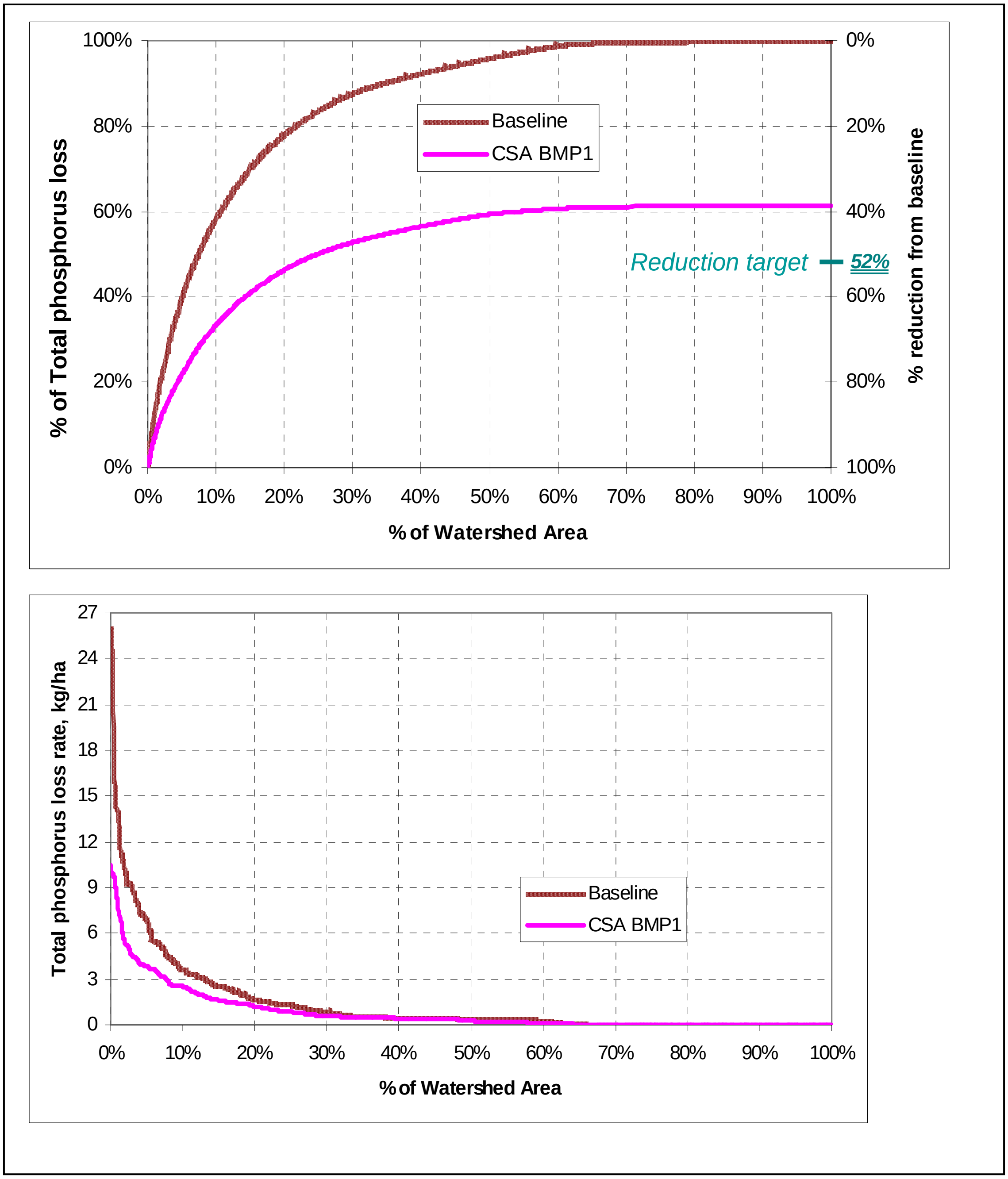


Figure 4-4. Potential reductions in phosphorus load that could be achieved using cover crops to corn fields (13% of watershed area) & filter strips on selected streams in the critical source areas (CSA BMP1) in the Rock River Watershed. A 52% reduction is shown as a potential phosphorus reduction goal from baseline.

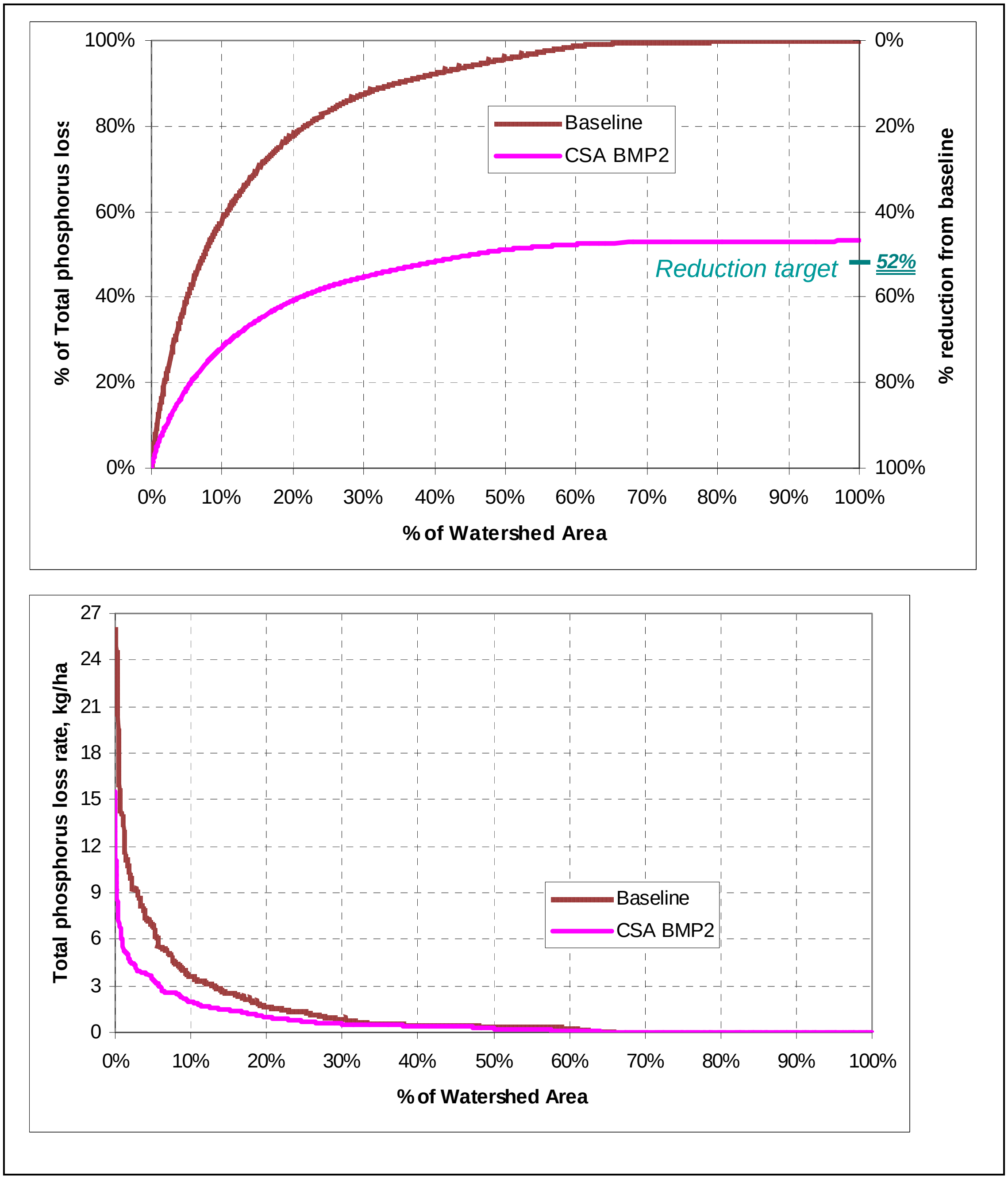


Figure 4-5. Potential reductions in phosphorus load that could be achieved using cover crops to corn fields (13% watershed area), erosion control measures to agricultural fields with slopes greater than 8%, & filter strips on selected stream in the critical source areas (CSA BMP2) in the Rock River Watershed. A 52% reduction is shown as a potential phosphorus reduction goal from baseline.

Based on the analysis shown in Figure 4-2, the general TMDL total phosphorus reduction goal of 52% cannot be met by implementing the two farm-level strategies alone (reduced phosphorus manure application and increased forage production). The management practice of minimum tillage to corn fields may reduce total phosphorus in the watershed by 22%, but it still falls short in achieving the reduction goal even at 100% implementation of the practice. Cover crops applied to corn fields yielded similar results.

When filter strips were applied in all identified streams, the total phosphorus of the watershed can be reduced by about 38% (Figure 4-3), a considerable amount towards achieving the 52% reduction goal selected previously. However, the 100% implementation rate assumed for buffer strips on all streams of the Rock River Watershed may be difficult to achieve for logistical and practical reasons. Moreover, based on the analysis of phosphorus loss sources on sub-basin basis, all sub-basins do not contribute equally to water impairment at the outlet of the study watershed; hence, filter strips may not be equally necessary for all sub-basins. Also, over time the effectiveness of buffer strips in trapping sediment and associated phosphorus may decline unless it is supported by other management practices, such as cover crops and erosion control measures, which reduce losses from upland sources.

When combinations of strategies are targeted to limited areas (and potentially with limited resources) that are identified as critical source areas of phosphorus loss, potentially higher phosphorus reductions can be achieved. For example, by combining cover crops on corn fields accounting only 13% of watershed area and filter strips on the main stream of the Rock River, 38% percent of reduction of total phosphorus can be achieved for the watershed (Figure 4-4). A 48% percent of reduction of total phosphorus can be achieved for the watershed by implementing appropriate corrective measures to the 20% critical source area of phosphorus loss in the watershed (Figure 4-5). Also, note the considerable reduction in the rate of total phosphorus loss due to the implementation of these strategies. These results indicated that the TMDL goal of 52% reduction in total phosphorus reduction can be met by focusing on areas with higher risk for phosphorus loss.

Overall, reduction goals can be attained by implementing more than one management practice on the upland areas identified as critical source areas for phosphorus losses (crop and animal production areas) and in other selected areas within the watershed and along the streams. While this study focused on a limited number of management strategies, the same approach can be used for other strategies (not included in this study) to assess their potential towards meeting a phosphorus reduction goal set at watershed level.

V-LESSONS LEARNED- A Framework for Nonpoint Phosphorus Accounting and Management

Targeting nonpoint phosphorus pollution sources and maintaining the economic viability of farms within the landscape of the water system are equally important in planning nonpoint source water pollution control. On the one hand, watershed-based planning is needed to identify pollution areas, plan corrective management changes, monitor water quality status, and quantify expected water quality benefits from future changes. Federal regulations, such as the Clean Water Act, recognize the watershed approach and its role in identifying impaired water bodies and in developing watershed plans, including the development of Total Maximum Daily Load (TMDL) programs to meet national water quality standards. With watershed-oriented management approaches, it is possible to objectively identify and quantify pollutant sources and to allocate resources and time to source areas where interventions will have the greatest effect on water quality. On the other hand, however, farm specific planning and management is still required to implement watershed plans, identify farm specific pollution sources, and plan appropriate farm management strategies as needed in order to control potential pollution sources while maintaining farm profitability.

In reality, a farm is the smallest management unit in the planning process, and every farm has unique challenges in achieving economic and water quality goals. Implementation of any management measures aimed at controlling phosphorus pollution are ultimately done on a farm-by farm basis. Also, controlling phosphorus build-up in the soils resulting from farm phosphorus imports exceeding exports, particularly in livestock production, is an important aspect of phosphorus pollution control efforts that are done on a farm-by-farm basis. Because long-term water quality control efforts within any watershed can be hindered by continuous phosphorus build-up in the soil, identifying and targeting the root cause of the phosphorus imbalance is critical in controlling phosphorus pollution. In conclusion, the importance of farm-level management must be emphasized in the process of nonpoint source water pollution control planning, and existing farm-level management (such as, Vermont’s Natural Resources Conservation Service (NRCS) 590 nutrient management planning efforts) or new farm-level management strategies and tools are needed to account for phosphorus mass balance in the planning process.

In this project, critical phosphorus imbalances were identified for three study dairy farms using a farm-scale model, Integrated Farm System Model, and this same model was used to examine potential strategies that could address these imbalance problems. Farm phosphorus imbalance occurs when phosphorus imports in purchased feed and fertilizers exceed phosphorus exports in milk, meat, or off-farm sales of harvested crops. The three farms studied in this project all had imbalances ranging from 4.9 lb/acre to 16.7 lb/acre across the farms. Though each study farm's case was different, critical sources of phosphorus imbalances common across the farms were: 1) high feeding levels of supplementary dietary mineral phosphorus, 2) sources and types of protein and energy supplements, and 3) levels of feed productivity and utilization of homegrown feeds in animal diets. Overfeeding mineral phosphorus supplements, low-productivity of homegrown feed (including grazing land) coupled with lower utilization of homegrown feed in the animal diet, and consequently relying on purchased protein and energy feed supplements to meet animal requirement for growth and production (milk, meat and others) were all contributors to the imbalances on these farms. Appropriate farm strategies required to address the phosphorus imbalance problems were developed for each farm by focusing on the specific problems each farm had. Results obtained from this study can set a benchmark for potential environmental and economic benefits of these farm management systems. These results and insights may also be transferred in general terms to other farms in Lake Champlain Basin with similar farm systems and sizes. However, direct extrapolations of results to all farms in the basin should not be made because of differences between farms in physical characteristics, mission, economic assets, and personal preferences.

While this study focused on three study farms with varying farm systems, the model-based approach employed is widely applicable, as is the methodology of representing alternative whole-farm system strategies to evaluate and quantify impacts of these strategies on farm-level phosphorus flows and farm profitability. Because of data and time limitations, application of this model to all farms in the basin, however, may not be practical. In this case, a simple accounting method of phosphorus mass balance should be incorporated in the farm management planning process in order to track phosphorus flows into and off the farms. For farms with phosphorus imbalance problems, appropriate and relevant farm strategies required to address the imbalance problem can be developed by focusing on the critical farm system areas identified in this study.

Moreover, for effective mitigation of nonpoint source phosphorus losses, management measures need to be targeted to areas that are high risk for phosphorus loss, critical source areas for phosphorus loss. For this purpose, identification of critical source areas for phosphorus loss that combine the sources and transport pathways is a key step. In this study, SWAT, a GIS-integrated watershed model, was a helpful tool for identifying and quantifying critical sources areas for phosphorus loss in the Rock River Watershed. Modeling results for this agricultural watershed showed that about 80% of total phosphorus loss occurred from only 24% of the watershed area, signifying the need for focused remedial measures on critical source areas of phosphorus loss. Landscape characteristics of these critical source areas for phosphorus loss were identified to comprise less ground cover, erosive soil type, steep slopes, and phosphorus availability. In addition, using the model outputs including maps of these critical source areas of phosphorus loss, fields for potential implementation of management strategies can be further selected based on their closeness to streams. As expected, fields with higher phosphorus loss rates that are close to streams are likely to have higher potential and immediate threat of phosphorus loss. Thus, they are recommended as the highest priority for management.

Depending on resource and data availability, this modeling approach can be applied in other agricultural watersheds of the Lake Champlain Basin. In any case, the insights and findings about the characteristics of CSAs identified in this study watershed can be transferred to other similar settings watersheds in the Lake Champlain Basin.

Because of data limitations and the scope of the modeling, this study did not estimate the potential phosphorus losses from manure storage and farmstead facility discharges or from stream channel degradation and gullies. Hence, conservation efforts should be complemented with onsite evaluation and inspection of individual farms and landscapes for these sources, and stream restoration for phosphorus reductions may also be appropriate. However, because unstable streams often originate from land erosion and runoff problems, stream restoration as a phosphorus reduction strategy should follow implementation of land based management practices.

Another important aspect of the watershed-level modeling framework developed in this study is its ability to assess the effectiveness of individual management strategies or combinations of management strategies for reducing phosphorus loss to streams, that is, quantitative determination of effectiveness of “what if” scenarios. A proactive, quantitative approach to examining potential reduction strategies offers the best hope for achieving the in-lake water quality standards that have been established.

The highest potential reduction of total phosphorus was achieved when management strategies were focused on critical sources of phosphorus loss. Focusing management strategies on areas where they are most needed will have the greatest potential for achieving the phosphorus reduction goals set at watershed level. Most importantly, limited resources can be allocated efficiently towards targeted areas to achieve maximum phosphorus loss reductions. Though not included in this study, costs of management strategies can have significant implications in making decisions on choices of management strategies and water quality tradeoffs. Hence the cost of management practices need to be included with the type of analysis demonstrated in this project.

While this study was focused a primarily agricultural watershed, the overall framework developed in this project can be applied in watershed with significant urban/suburban development as well. In urban/suburban watersheds, the smallest planning units become neighborhoods or municipal administration units instead of the farms in agricultural watersheds. Therefore, watershed-based nonpoint phosphorus control planning should integrate neighborhoods or/and municipal administration planning in order to include local development plans, ordinances and regulations. Similar to what was done in agricultural areas, a modeling framework appropriate to urban/suburban watershed should identify the sources and transport pathways controlling phosphorus export from developments so that optimal remedial strategies can be targeted to these critical source areas of pollution.

There are a variety of phosphorus sources in urban/suburban area, including over-application of fertilizer to lawns and gardens, phosphorus leaching from building materials and from road surfaces, storm drain discharges, and stream erosion induced by increases in discharge in urban streams. Because runoff control from impervious areas is essential in order for streams to readjust to a more stable configuration, upland conservation measures should be put in place before stream restoration for phosphorus reductions.

A watershed modeling approach applicable to urban/suburban watersheds, similar to the one used in the Rock River Watershed, can be used to estimate nonpoint source phosphorus loads and quantify the impact of urban management strategies. Potential management strategies for implementation can be developed based on their relevance to the problem, effectiveness based on scientific literature review and field studies, and practicality based on consultation with local neighborhood or municipal officials and regulators. Just as in agricultural watersheds, management practices should be targeted to critical watershed areas for phosphorus loss. Since development will continue to occur in appropriate areas, regulations and inspections to achieve net zero phosphorus loss from construction sites will be necessary in addition to putting management practices in place in existing developments. Ultimately scenarios could be run that combine phosphorus management strategies for developed lands and agricultural lands since many watersheds in the Lake Champlain Basin include a mixture of a significant amount of both of these land uses.

The results of this project clearly demonstrate that measurable reductions in nonpoint source phosphorus loading are possible. A strategic approach to interventions based on a mass balance approach on farms, combined with targeting critical source areas and phosphorus accounting will lead to the most effective use of resources over the long term.

REFERENCES

Andersen, J. A., G. Alagarswamy, C. A. Rotz, J. T. Ritchie, and A. W. Lebaron. 2001. Weather impacts on maize, soybean, and alfalfa production in the Great Lakes Region 1895-1996. Agronomy Journal 93: 1059-1070.

Assleman NEM. 2000. Fitting and interpretation of sediment rating curves. Journal of Hydrology. 23(4): 228-248.

Borah, D. K., and M. Bera. 2004. Water-scale hydrologic and nonpoint-source pollution models: review of applications. *Trans. ASAE*. 47(3): 789-803.

Byers HL, Cabrera ML, Matthews MK, Franklin DH, Andrae JG, Radcliffe DE, McCann MA, Kuykendall HA, Hoveland CS, and Calvert VH II. 2005. Phosphorus, Sediment, and *Escherichia coli* loads in unfenced streams of the Georgia Piedmont, USA**.** Journal Environmental Quality. 34 (6).

Cerosaletti, P. E., D. G. Fox, and L. E. Chase. 2004. Phosphorus reduction through precision feeding of dairy cattle. J. Dairy Sci. 87:2314-2323.

Cohn TA, Caulder DL, Gilroy EJ, Zynjuk LD and Summers RM. 1992. The validity of a simple statistical model for estimating fluvial constituent loads: an empirical study involving nutrients loads entering Chesapeake Bay. Water Resources Research. 28 (9): 2353-2363.

Dabney, S. M., J. A. Delgado, and D. W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Comm. Soil Sci. Plant. Anal. 32:1211-1250.

Davis Rl, Zhang H, Schro. JL, Wang JJ, Payton WE and Zazulak A. 2005. Soil characteristics and phosphorus level effect on phosphorus loss in runoff. Journal Environmental Quality. 34 (5): 1640-50.

Di Luzio, M., R. Srinivasan, and J.G. Arnold. 2002. Integration of watershed tools and SWAT model into BASINS. Journal of American Water Resources Association 38(4):1127-1141.

Dou, Z., F. K. Knowlton, R. A. Kohn, Z. Wu, L. D. Satter, G. Zhang, J. D. Toth, and J. D. Ferguson. 2002. Phosphorus characteristics of dairy feces affected by diets. J. Environ. Qual. 31: 2058-2065.

Ebeling, A. M., L. G. Bundy, T. W. Andraski, and J. M. Powell. 2002. Dairy diet phosphorus effects on phosphorus losses in runoff from land-applied manure. Soil Sci. Am. J. 66:284-291.

Gassman, P.W., M.R. Reyes, C.H. Green, and J.G. Arnold. 2007. The Soil and Water Assessment Tool: historical development, applications, and future research directions. *Trans .ASABE* 50(4): 1211-1250.

Ghebremichael, L.T., P.E. Cerosaletti, T.L. Veith, C.A. Rotz, J.M. Hamlett, and W.J. Gburek. 2007. Economic and phosphorus-related effects of precision feeding and forage management at a farm-scale. Journal of Dairy Science 90(8):3700-3715.

Ghebremichael, L.T., Veith, T.L., Hamlett, J.M., Gburek, W. 2008. Precision feeding and forage management effects on phosphorus loss modeled at a watershed scale. Journal of Soil and Water Conservation. 63(5):28-291.

Gitau, M.W., W.J.Gburek, and A.R.Jarrett. 2005. A tool for estimating best management practice effectiveness for phosphorus pollution control. J. Soil and Water Cons. 60(1): 1-10.

Jones, C. A., C. V. Cole, A. N. Sharpley, and J. R. Williams. 1984. A simplified soil and plant phosphorus model: I. Documentation. Soil Sci. Am. J. 48:800-805.

Lake Champlain Basin Study. 1979. Shaping the Future of Lake Champlain. The Final Report of the Lake Champlain Basin Study. Waterbury, Vermont and Albany, New York.: States of Vermont and New York and the New England River Basins Commission.

Lake Champlain Program. 2002. Lake Champlain Phosphorus TMDL. Waterbury, Vermont and Albany, New York.: Vermont Agency of Natural Resources and Department of Environmental conservation and New York State Department of Environmental conservation. Available at: www.vtwaterquality.org/lakes/htm/lp_phosphorus.htm. Accessed 3 September 2009.

Lake Champlain Basin Program. 2006. A 15th Anniversary Report about Lake Champlain's Restoration: Progress 2006. Grand Isle, VT.: Lake Champlain Basin Program.

Lake Champlain Basin Program. 2008. State of the Lake and Ecosystem Indicators Report-2008. Grand Isle, VT. : Lake Champlain Basin Program.

Lal, R., M. Griffin, J. Apt, L. Lave, and M. G. Morgan. 2004. Managing soil carbon. Science, 304(5669):393.

Lanyon, L.E. 1992. Implication of dairy herd size for farm material transport, plant nutrient management, and water quality. Journal of Dairy Science 75:334-344.

Martinez J and Rango A. 1989. Merits of statistical criteria for the performance of hydrological models. Water Resources Bulletin. 25(2): 421-432.

Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans.ASABE* 50(3): 885-900.

Mueller DH, Wendt RC, Daniel TC (1984) Phosphorus losses as affected by tillage and manure application. Soil Sci Soc Am J 48:901–905

Mutchler, C. K., and L. L. McDowell. 1990. Soil loss from cotton with winter cover crops. Trans. ASAE 33:432-436.

National Research Council. 2001. Nutrient requirements of dairy cattle. 7th ed. Natl. Acad. Press, Washington, DC.

Neitsch, S. L., J. G. Arnold, T. R. Kiniry, and J. R. Williams. 2002a. Soil and Water Assessment Tool:Users Manual Version 2000. Report No. TR-192. College Station, Texas: Texas Water Resources Institute.

Neitsch, S. L., J. G. Arnold, T. R. Kiniry, J. R. Williams, and K. W. King. 2002b. Soil and Water Assessment Tool. Theoretical Documentation. Report # TR-191. College Station, Texas: Texas Water Resources Institute.

Quilbe, R., A.N. Rousseau, M. Duchemin, A. Poulin, G. Gangbazo, and J-P. Villeneuve. 2006. Selecting a calculation method to estimate sediment and nutrient loads in streams: Application to the Beaurivage River (Quebec, Canada), *Journal of Hydrology* 326 (2006), pp. 295–310.

Reicosky, D. C., and F. Forcella. 1998. Cover crop and soil quality interactions in agroecosystems. J. Soil Water Conservat. 53:224-229.

Rotz, C.A., and C.U. Coiner. 2006. Integrated Farm System Model (IFSM): Reference Manual Version 2.0. Agricultural Research Service, USDA. http://www.ars.usda.gov/Main/docs.htm?docid=8519

Rotz, C. A., D. R. Mertens, D. R. Buckmaster, M. S. Allens, and J. H. Harrison. 1999. A dairy herd model for use in whole farm simulations. J. Dairy Sci. 82: 2826-2840.

Rotz, C. A., W. G. Roth, K. J. Soder, and R. R. Schnabel. 2001. Economic and environmental implications of soybean production and use on Pennsylvania dairy farms. Agronomy Journal 93: 418-428.

Rotz, C. A., A. N. Sharpley, L. D. Shatter, W. J. Gburek, and M. A. Sanderson. 2002. Production and feeding strategies for phosphorus management on dairy farms. J. Dairy Sci. 85: 3142-3153.

Santhi, C., J.G. Arnold, J.R. Williams, L.M. Hauck, and W.A. Dugas. 2001. Application of a watershed model to evaluate management effects on point and nonpoint source pollution. Transactions of the ASAE 44(6):1559-1570.

Sharpley A.N, and Smith SJ. 1994. Wheat tillage and water quality in the southern plains. Soil Tillage Res 30:33–38.

Sharpley, A. N., and S. Rekolainen. 1997. Chapter 1: Phosphorus in agriculture and its environmental implications. 1-53. Tunney, H., and O. T. Carton, eds. Oxon, U.K. CAB International.

Satter, L.D., and Z. Wu. 1999. Reducing manure phosphorus by dairy diet manipulation. In Proc. in Proc. Cornell Nutr. Conf. Feed Manuf. 183-192. Ithaca, NY: Cornell University.

Sedorovich, D. M., C. A. Rotz, and P. A. Vadas. 2005. Predicting management effects on phosphorus loss from farming systems. ASAE paper No 0530053. St. Joseph, MI: ASAE.

Shipley, P. R., J. J. Messinger, and A. M. Decker. 1992. Conserving residual corn fertilizer nitrogen with winter cover crops. Agron. J. 84:869-876.

Singh KP and Durgunoglu A. 1989. Developing accurate and reliable stream sediment yields. In sediments and the Environment. IHAS Publication. 184: 193-199.

Soder, K. J., and C. A. Rotz. 2001. Economic and environmental impact of four levels of concentrate supplementation in grazing dairy herds. J. Dairy Sci. 84:2560-2572.

Vadas PA, Kleinman PJA, Sharpley AN, and Turner BL. 2005. Relating soil phosphorus to dissolved phosphorus in runoff: A single extraction coefficient for water quality modeling. Journal Environmental Quallity. 34 (2).

Williams, J. R., and H. D. Berndt. 1977. Sediment yield prediction based on watershed hydrology. *Trans. ASAE*. 1100-1104.

Williams, J. R. 1995. Chapter 25: The EPIC Model. In *Computer Models of Watershed Hydrology*. V. P. Singh, ed. Highlands Ranch, Colo.: Water Resources Publications.

Wischmeier, W. H., and D. D. Smith. 1978. Predicting rainfall erosion losses- A guide to conservation planning. Agriculture Handbook Number 537. USDA.

Wright, A. L., and F. M. Hons. 2004. Soil aggregation and carbon and nitrogen storage under soybean cropping sequences. Soil Sci. Soc. Am. J. 68:507-513.

Appendix A

Table in the next pages presents 7-year (2001-2008) annual average SWAT outputs of total phosphorus (TP) and sediment losses summarized by unique response units, HURs (with common landuse, soil, and slope combinations). Additionally, data are presented to demonstrate the percentage of watershed area corresponding to the amount and percentage of TP and sediment losses. Also in the table, depicting predicted TP and sediment, HRUs are ranked from high to low based on their SWAT-predicted TP loss rates, and cumulative TP are presented along with loss rates. This type of data analysis was useful in identifying HRUs with higher TP and in determining target level for mitigating TP losses.

Key abbreviations used are: TP = Total phosphorus; SS= sediment; CSIL= corn; AG, AGR, and AGRI = agricultural crops; URLD = buildings and roads; FRMS = farmsteads; PAST= pasture; Open = open areas near buildings; RNGB = rangeland; WETL = wetland; WATR = waterbodies; FRST = forest.

Landuse-soil-slope	Area, km^2	TP, Kg	SS, Tonnes, T	TP kg/ha	Sed T/ha	Cumulative TP, kg	% of cumulative TP	Cumulative Area, km^2	% of cumulative area
CSIL_D_15-9999	0.032	42.43	261.11	13.11	80.69	42.43	0.6%	0.032	0.0%
CSIL_D_8-15	0.294	326.83	1876.73	11.13	63.93	369.26	4.9%	0.326	0.5%
CSIL_C_15-9999	0.096	95.65	441.14	9.97	45.99	464.91	6.2%	0.422	0.6%
CSIL_B_8-15	0.111	101.70	569.72	9.20	51.53	566.61	7.6%	0.532	0.8%
CSIL_B_15-9999	0.013	11.71	63.96	8.94	48.84	578.32	7.7%	0.545	0.8%
CSIL_C_8-15	0.656	574.24	2500.28	8.76	38.13	1152.56	15.4%	1.201	1.7%
CSIL_D_3-8	1.897	1056.60	4891.44	5.57	25.79	2209.16	29.5%	3.098	4.4%
AGRI_C_15-9999	0.014	6.31	42.88	4.43	30.08	2215.47	29.6%	3.112	4.4%
CSIL_A_15-9999	0.003	1.50	6.41	4.33	18.50	2216.97	29.6%	3.116	4.4%
CSIL_A_8-15	0.033	14.07	60.29	4.30	18.41	2231.04	29.8%	3.148	4.4%
CSIL_C_3-8	2.270	973.44	3892.26	4.29	17.15	3204.49	42.8%	5.419	7.6%
CSIL_B_3-8	0.325	136.78	620.83	4.21	19.12	3341.26	44.6%	5.743	8.1%
AG_C_15-9999	0.453	183.01	1655.49	4.04	36.51	3524.27	47.0%	6.197	8.7%
AGR_D_8-15	0.003	1.32	6.70	3.80	19.34	3525.59	47.0%	6.200	8.8%
AGRI_C_8-15	0.050	16.63	108.93	3.32	21.75	3542.22	47.3%	6.250	8.8%
URLD_D_8-15	0.192	63.06	748.15	3.28	38.92	3605.27	48.1%	6.443	9.1%
AG_D_8-15	0.596	194.87	1878.86	3.27	31.55	3800.14	50.7%	7.038	9.9%
URLD_C_15-9999	0.197	64.34	737.48	3.26	37.39	3864.48	51.6%	7.235	10.2%
URLD_B_15-9999	0.026	8.49	156.64	3.24	59.80	3872.96	51.7%	7.262	10.2%
AG_C_8-15	1.161	365.00	2715.28	3.14	23.39	4237.97	56.5%	8.422	11.9%
AGRI_D_8-15	0.013	3.80	36.80	2.99	28.95	4241.76	56.6%	8.435	11.9%
URLD_C_8-15	0.449	127.92	1233.26	2.85	27.48	4369.68	58.3%	8.884	12.5%
FRMS_D_8-15	0.020	5.59	82.35	2.85	41.91	4375.28	58.4%	8.903	12.6%
AG_D_15-9999	0.179	50.33	562.37	2.82	31.46	4425.61	59.0%	9.082	12.8%
AG_B_15-9999	0.041	11.14	138.96	2.73	34.03	4436.75	59.2%	9.123	12.9%
AGR_D_3-8	0.042	11.19	49.45	2.69	11.89	4447.95	59.3%	9.165	12.9%
FRMS_D_15-9999	0.007	1.73	26.23	2.64	40.05	4449.68	59.4%	9.171	12.9%
URLD_D_3-8	0.340	87.77	593.31	2.58	17.46	4537.44	60.5%	9.511	13.4%
URLD_D_15-9999	0.114	28.39	416.59	2.49	36.54	4565.84	60.9%	9.625	13.6%
FRMS_C_8-15	0.046	11.51	84.18	2.49	18.21	4577.35	61.1%	9.671	13.6%
AGRI_D_15-9999	0.002	0.37	3.40	2.39	22.06	4577.72	61.1%	9.673	13.7%
FRMS_D_3-8	0.033	7.50	73.42	2.29	22.42	4585.21	61.2%	9.705	13.7%
AG_A_15-9999	0.025	5.77	38.04	2.27	14.96	4590.98	61.3%	9.731	13.7%
FRMS_C_15-9999	0.008	1.88	11.73	2.21	13.83	4592.86	61.3%	9.739	13.7%
AG_A_8-15	0.069	15.05	96.70	2.17	13.95	4607.91	61.5%	9.809	13.8%
AG_D_3-8	1.146	246.74	1509.56	2.15	13.17	4854.65	64.8%	10.955	15.5%
AG_B_8-15	0.086	17.15	162.79	1.99	18.87	4871.80	65.0%	11.041	15.6%
CSIL_A_3-8	0.099	19.67	75.21	1.98	7.57	4891.47	65.3%	11.140	15.7%
CSIL_D_0-3	3.382	613.53	2287.63	1.81	6.76	5505.00	73.5%	14.522	20.5%
URLD_A_8-15	0.012	2.16	17.77	1.81	14.88	5507.16	73.5%	14.534	20.5%
OPEN_D_15-9999	0.021	3.68	67.84	1.77	32.61	5510.84	73.5%	14.555	20.5%
FRMS_C_3-8	0.116	20.52	129.25	1.76	11.11	5531.36	73.8%	14.671	20.7%
AGRI_D_3-8	0.016	2.75	15.68	1.74	9.93	5534.12	73.8%	14.687	20.7%
URLD_B_8-15	0.041	7.11	90.41	1.74	22.14	5541.23	73.9%	14.728	20.8%
URLD_C_3-8	0.715	114.01	753.24	1.60	10.54	5655.24	75.5%	15.443	21.8%
AGRI_C_3-8	0.065	10.00	48.45	1.53	7.40	5665.24	75.6%	15.508	21.9%
FRMS_A_8-15	0.002	0.29	1.73	1.52	8.98	5665.54	75.6%	15.510	21.9%

Landuse-soil-slope	Area, km^2	TP, Kg	SS, Tonnes, T	TP kg/ha	Sed T/ha	Cumulative TP, kg	% of cumulative TP	Cumulative Area, km^2	% of cumulative area
AG_C_3-8	1.742	255.74	1381.99	1.47	7.94	5921.27	79.6%	17.252	24.3%
CSIL_C_0-3	2.286	330.37	1142.95	1.45	5.00	6251.64	83.4%	19.537	27.6%
OPEN_D_3-8	0.002	0.32	1.44	1.37	6.24	6251.96	83.4%	19.540	27.6%
OPEN_B_8-15	0.0001	0.05	0.42	1.33	10.95	6252.01	83.4%	19.540	27.6%
CSIL_B_0-3	0.443	58.36	209.94	1.32	4.74	6310.37	84.2%	19.983	28.2%
FRMS_D_0-3	0.029	3.71	18.31	1.30	6.42	6314.08	84.2%	20.011	28.2%
FRMS_B_8-15	0.007	0.80	3.70	1.22	5.66	6314.88	84.3%	20.018	28.3%
URLD_D_0-3	0.236	27.96	135.72	1.18	5.75	6342.85	84.6%	20.254	28.6%
AGR_C_3-8	0.021	2.43	14.85	1.15	7.01	6345.28	84.7%	20.275	28.6%
URLD_B_3-8	0.043	4.92	49.03	1.14	11.36	6350.20	84.7%	20.318	28.7%
AG_B_3-8	0.105	11.83	80.79	1.13	7.68	6362.03	84.9%	20.423	28.8%
OPEN_D_8-15	0.003	0.34	4.33	1.12	14.06	6362.38	84.9%	20.426	28.8%
FRMS_B_15-9999	0.001	0.13	0.53	1.09	4.60	6362.50	84.9%	20.427	28.8%
FRMS_B_3-8	0.017	1.82	11.70	1.07	6.90	6364.32	84.9%	20.444	28.9%
FRMS_A_3-8	0.007	0.74	3.89	1.07	5.62	6365.07	84.9%	20.451	28.9%
URLD_A_15-9999	0.001	0.08	0.50	1.03	6.48	6365.15	84.9%	20.452	28.9%
AGR_D_0-3	0.049	4.71	17.58	0.95	3.57	6369.85	85.0%	20.501	28.9%
URLD_A_3-8	0.044	4.19	27.64	0.95	6.24	6374.04	85.0%	20.546	29.0%
AG_D_0-3	1.774	153.95	636.06	0.87	3.59	6527.98	87.1%	22.319	31.5%
AG_A_3-8	0.096	8.21	42.25	0.86	4.40	6536.20	87.2%	22.415	31.6%
PAST_C_15-9999	0.220	17.12	7.06	0.78	0.32	6553.32	87.4%	22.635	31.9%
PAST_B_8-15	0.012	0.84	0.21	0.72	0.18	6554.15	87.4%	22.646	32.0%
CSIL_A_0-3	0.165	11.83	33.41	0.72	2.03	6565.98	87.6%	22.811	32.2%
PAST_B_15-9999	0.0001	0.03	0.00	0.69	0.09	6566.01	87.6%	22.812	32.2%
PAST_D_8-15	0.120	8.18	3.31	0.68	0.28	6574.19	87.7%	22.931	32.4%
PAST_D_15-9999	0.035	2.32	1.02	0.66	0.29	6576.51	87.7%	22.966	32.4%
PAST_C_8-15	0.454	28.98	8.97	0.64	0.20	6605.49	88.1%	23.421	33.1%
OPEN_A_8-15	0.000	0.02	0.14	0.64	3.57	6605.52	88.1%	23.421	33.1%
FRMS_C_0-3	0.081	5.13	20.04	0.63	2.48	6610.65	88.2%	23.502	33.2%
PAST_B_3-8	0.017	1.04	0.09	0.63	0.05	6611.68	88.2%	23.519	33.2%
OPEN_C_3-8	0.001	0.05	0.26	0.62	3.32	6611.73	88.2%	23.519	33.2%
OPEN_B_3-8	0.0001	0.02	0.12	0.62	3.02	6611.75	88.2%	23.520	33.2%
PAST_B_0-3	0.002	0.12	0.00	0.61	0.01	6611.87	88.2%	23.522	33.2%
URLD_C_0-3	0.351	21.11	104.45	0.60	2.98	6632.98	88.5%	23.872	33.7%
AGR_C_8-15	0.001	0.05	0.24	0.60	3.11	6633.02	88.5%	23.873	33.7%
PAST_A_3-8	0.002	0.14	0.00	0.59	0.01	6633.16	88.5%	23.875	33.7%
PAST_A_8-15	0.000	0.02	0.00	0.58	0.01	6633.18	88.5%	23.876	33.7%
PAST_D_3-8	0.246	14.32	2.79	0.58	0.11	6647.50	88.7%	24.121	34.0%
FRMS_B_0-3	0.012	0.67	2.79	0.56	2.34	6648.17	88.7%	24.133	34.1%
PAST_C_3-8	0.642	34.93	4.29	0.54	0.07	6683.10	89.2%	24.775	35.0%
AG_C_0-3	0.997	53.88	237.71	0.54	2.39	6736.97	89.9%	25.772	36.4%
PAST_D_0-3	0.100	5.32	0.32	0.53	0.03	6742.30	90.0%	25.871	36.5%
FRMS_A_0-3	0.006	0.32	1.09	0.52	1.77	6742.62	90.0%	25.878	36.5%
HAY_B_15-9999	0.034	1.77	0.89	0.52	0.26	6744.39	90.0%	25.912	36.6%
PAST_C_0-3	0.213	10.98	0.40	0.52	0.02	6755.37	90.1%	26.125	36.9%
HAY_B_8-15	0.198	9.72	3.62	0.49	0.18	6765.09	90.3%	26.323	37.2%
HAY_A_8-15	0.035	1.60	0.34	0.46	0.10	6766.69	90.3%	26.358	37.2%
HAY_B_3-8	0.388	17.16	2.69	0.44	0.07	6783.85	90.5%	26.746	37.7%

Landuse-soil-slope	Area, km^2	TP, Kg	SS, Tonnes, T	TP kg/ha	Sed T/ha	Cumulative TP, kg	% of cumulative TP	Cumulative Area, km^2	% of cumulative area
HAY_C_15-9999	0.296	12.95	6.34	0.44	0.21	6796.80	90.7%	27.042	38.2%
HAY_C_8-15	1.471	63.53	26.09	0.43	0.18	6860.33	91.5%	28.513	40.2%
HAY_A_3-8	0.128	5.52	0.43	0.43	0.03	6865.85	91.6%	28.641	40.4%
HAY_A_0-3	0.290	12.14	0.28	0.42	0.01	6877.98	91.8%	28.931	40.8%
HAY_B_0-3	0.214	8.77	0.35	0.41	0.02	6886.76	91.9%	29.145	41.1%
HAY_D_8-15	0.631	25.81	16.67	0.41	0.26	6912.56	92.2%	29.777	42.0%
AGRI_D_0-3	0.003	0.14	0.88	0.41	2.55	6912.71	92.2%	29.780	42.0%
HAY_A_15-9999	0.005	0.21	0.05	0.40	0.09	6912.92	92.2%	29.785	42.0%
AGRI_C_0-3	0.022	0.84	3.45	0.38	1.57	6913.76	92.2%	29.807	42.1%
HAY_C_3-8	3.750	143.78	31.25	0.38	0.08	7057.54	94.2%	33.558	47.4%
HAY_D_3-8	3.055	112.37	38.97	0.37	0.13	7169.91	95.7%	36.613	51.7%
HAY_D_15-9999	0.101	3.58	2.45	0.36	0.24	7173.49	95.7%	36.714	51.8%
HAY_C_0-3	3.039	107.56	7.53	0.35	0.02	7281.05	97.1%	39.753	56.1%
AG_B_0-3	0.079	2.65	13.19	0.34	1.67	7283.70	97.2%	39.832	56.2%
URLD_A_0-3	0.129	4.28	23.10	0.33	1.78	7287.98	97.2%	39.962	56.4%
HAY_D_0-3	3.918	129.45	12.59	0.33	0.03	7417.43	99.0%	43.880	61.9%
URLD_B_0-3	0.014	0.42	2.15	0.30	1.51	7417.86	99.0%	43.894	61.9%
AGR_C_0-3	0.002	0.04	0.19	0.29	1.26	7417.90	99.0%	43.895	61.9%
OPEN_B_0-3	0.0001	0.01	0.05	0.28	1.23	7417.91	99.0%	43.896	62.0%
OPEN_A_15-9999	0.0001	0.01	0.04	0.25	1.09	7417.92	99.0%	43.896	62.0%
OPEN_A_8-15	0.0001	0.01	0.04	0.25	1.09	7417.93	99.0%	43.897	62.0%
AG_A_0-3	0.150	3.67	13.97	0.24	0.93	7421.60	99.0%	44.046	62.2%
OPEN_C_15-9999	0.084	2.05	5.09	0.24	0.60	7423.65	99.0%	44.131	62.3%
OPEN_D_0-3	0.000	0.01	0.04	0.24	1.09	7423.66	99.1%	44.131	62.3%
OPEN_B_15-9999	0.034	0.64	1.99	0.19	0.60	7424.30	99.1%	44.165	62.3%
OPEN_C_8-15	0.117	2.09	4.88	0.18	0.41	7426.39	99.1%	44.282	62.5%
OPEN_B_8-15	0.025	0.43	1.19	0.17	0.47	7426.82	99.1%	44.307	62.5%
OPEN_D_3-8	0.076	1.30	2.32	0.17	0.30	7428.12	99.1%	44.384	62.6%
OPEN_D_8-15	0.059	0.85	2.30	0.15	0.39	7428.97	99.1%	44.442	62.7%
OPEN_C_3-8	0.220	2.94	5.03	0.13	0.23	7431.91	99.2%	44.662	63.0%
OPEN_C_0-3	0.146	1.95	3.01	0.13	0.21	7433.86	99.2%	44.808	63.2%
OPEN_D_0-3	0.151	2.01	2.03	0.13	0.13	7435.87	99.2%	44.960	63.5%
OPEN_B_3-8	0.023	0.30	0.55	0.13	0.24	7436.16	99.2%	44.983	63.5%
OPEN_B_0-3	0.011	0.13	0.20	0.13	0.19	7436.30	99.2%	44.994	63.5%
OPEN_D_15-9999	0.053	0.60	1.94	0.11	0.37	7436.90	99.2%	45.047	63.6%
OPEN_A_0-3	0.023	0.23	0.55	0.10	0.24	7437.13	99.2%	45.070	63.6%
WETL_B_15-9999	0.004	0.04	0.15	0.10	0.40	7437.17	99.2%	45.073	63.6%
OPEN_A_3-8	0.008	0.08	0.16	0.10	0.20	7437.25	99.2%	45.082	63.6%
WETL_D_3-8	0.054	0.49	0.26	0.09	0.05	7437.73	99.2%	45.135	63.7%
WETL_D_8-15	0.052	0.46	0.09	0.09	0.02	7438.19	99.2%	45.187	63.8%
WETL_D_15-9999	0.064	0.54	0.15	0.09	0.02	7438.74	99.3%	45.251	63.9%
WETL_D_0-3	0.169	1.43	0.12	0.08	0.01	7440.17	99.3%	45.420	64.1%
WETL_C_8-15	0.010	0.09	0.20	0.08	0.19	7440.25	99.3%	45.431	64.1%
WETL_B_8-15	0.003	0.02	0.08	0.08	0.26	7440.28	99.3%	45.434	64.1%
RNGB_D_15-9999	0.077	0.60	1.35	0.08	0.17	7440.88	99.3%	45.511	64.2%
RNGB_C_15-9999	0.069	0.53	1.51	0.08	0.22	7441.41	99.3%	45.580	64.3%
RNGB_D_8-15	0.095	0.71	1.24	0.07	0.13	7442.12	99.3%	45.675	64.5%
WETL_C_3-8	0.019	0.14	0.18	0.07	0.09	7442.26	99.3%	45.694	64.5%

Landuse-soil-slope	Area, km^2	TP, Kg	SS, Tonnes, T	TP kg/ha	Sed T/ha	Cumulative TP, kg	% of cumulative TP	Cumulative Area, km^2	% of cumulative area
WETL_C_15-9999	0.005	0.04	0.08	0.07	0.14	7442.29	99.3%	45.699	64.5%
WETL_C_0-3	0.023	0.16	0.08	0.07	0.04	7442.46	99.3%	45.722	64.5%
RNGB_C_8-15	0.089	0.56	1.14	0.06	0.13	7443.02	99.3%	45.811	64.7%
RNGB_D_3-8	0.128	0.72	0.55	0.06	0.04	7443.74	99.3%	45.939	64.8%
WETL_B_3-8	0.002	0.01	0.01	0.05	0.08	7443.76	99.3%	45.941	64.8%
RNGB_D_0-3	0.204	1.06	0.10	0.05	0.01	7444.82	99.3%	46.145	65.1%
RNGB_C_3-8	0.115	0.56	0.58	0.05	0.05	7445.38	99.3%	46.260	65.3%
RNGB_B_15-9999	0.012	0.05	0.19	0.04	0.16	7445.43	99.3%	46.272	65.3%
RNGB_C_0-3	0.042	0.19	0.03	0.04	0.01	7445.62	99.3%	46.314	65.4%
WETL_B_0-3	0.002	0.01	0.00	0.04	0.00	7445.63	99.3%	46.316	65.4%
RNGB_B_8-15	0.017	0.05	0.10	0.03	0.06	7445.68	99.3%	46.333	65.4%
FRST_D_15-9999	3.417	9.58	40.04	0.03	0.12	7455.26	99.5%	49.751	70.2%
RNGB_B_3-8	0.013	0.03	0.02	0.03	0.02	7455.30	99.5%	49.764	70.2%
RNGB_B_0-3	0.002	0.00	0.00	0.02	0.00	7455.30	99.5%	49.765	70.2%
FRST_D_8-15	2.883	6.64	23.98	0.02	0.08	7461.95	99.6%	52.648	74.3%
FRST_C_15-9999	2.989	6.69	26.58	0.02	0.09	7468.63	99.7%	55.637	78.5%
FRST_B_15-9999	0.233	0.52	2.45	0.02	0.10	7469.15	99.7%	55.870	78.9%
FRST_C_8-15	2.801	5.77	17.16	0.02	0.06	7474.92	99.7%	58.672	82.8%
FRST_D_0-3	2.692	5.30	2.49	0.02	0.01	7480.22	99.8%	61.364	86.6%
FRST_D_3-8	2.767	5.06	9.35	0.02	0.03	7485.28	99.9%	64.131	90.5%
FRST_C_0-3	2.094	3.65	1.47	0.02	0.01	7488.93	99.9%	66.225	93.5%
FRST_B_8-15	0.232	0.39	1.34	0.02	0.06	7489.32	99.9%	66.457	93.8%
FRST_C_3-8	3.068	4.93	6.83	0.02	0.02	7494.25	100.0%	69.524	98.1%
FRST_B_3-8	0.246	0.30	0.41	0.01	0.02	7494.55	100.0%	69.770	98.5%
WETL_A_8-15	0.004	0.01	0.01	0.01	0.02	7494.56	100.0%	69.775	98.5%
FRST_B_0-3	0.177	0.20	0.07	0.01	0.00	7494.75	100.0%	69.951	98.7%
WETL_A_3-8	0.002	0.00	0.00	0.01	0.01	7494.76	100.0%	69.953	98.7%
WETL_A_0-3	0.009	0.01	0.00	0.01	0.00	7494.77	100.0%	69.963	98.7%
WETL_A_15-9999	0.001	0.00	0.00	0.01	0.00	7494.77	100.0%	69.963	98.7%
RNGB_A_15-9999	0.005	0.00	0.00	0.00	0.01	7494.77	100.0%	69.969	98.7%
RNGB_A_0-3	0.004	0.00	0.00	0.00	0.00	7494.77	100.0%	69.973	98.8%
RNGB_A_8-15	0.007	0.00	0.00	0.00	0.00	7494.77	100.0%	69.980	98.8%
RNGB_A_3-8	0.008	0.00	0.00	0.00	0.00	7494.77	100.0%	69.988	98.8%
FRST_A_15-9999	0.129	0.02	0.02	0.00	0.00	7494.79	100.0%	70.117	99.0%
FRST_A_8-15	0.150	0.02	0.03	0.00	0.00	7494.81	100.0%	70.267	99.2%
FRST_A_3-8	0.154	0.02	0.01	0.00	0.00	7494.83	100.0%	70.421	99.4%
FRST_A_0-3	0.297	0.03	0.00	0.00	0.00	7494.86	100.0%	70.717	99.8%
WATR_D_8-15	0.006	0.00	0.00	0.00	0.00	7494.86	100.0%	70.723	99.8%
WATR_D_3-8	0.012	0.00	0.00	0.00	0.00	7494.86	100.0%	70.735	99.8%
WATR_D_15-9999	0.003	0.00	0.00	0.00	0.00	7494.86	100.0%	70.738	99.8%
WATR_D_0-3	0.110	0.00	0.00	0.00	0.00	7494.86	100.0%	70.848	100.0%
WATR_C_8-15	0.002	0.00	0.00	0.00	0.00	7494.86	100.0%	70.850	100.0%
WATR_C_3-8	0.005	0.00	0.00	0.00	0.00	7494.86	100.0%	70.855	100.0%
WATR_C_15-9999	0.0001	0.00	0.00	0.00	0.00	7494.86	100.0%	70.855	100.0%
WATR_C_0-3	0.001	0.00	0.00	0.00	0.00	7494.86	100.0%	70.856	100.0%