UNCERTAINTY ANALYSIS
IN
NONPOINT SOURCE WATER QUALITY MANAGEMENT

by:

JEANNE S. YULIANTI

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Submitted to the faculty of Graduate Studies
of the University of Manitoba in Partial
Fulfilment of the Requirements for the Degree of
Doctor of Philosophy

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Nutrition	0570
Obstetrics and Gynecology	0380
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Ophthalmology	0381
Pathology	0571
Pharmacology	0419
Pharmacy	0572
Physical Therapy	0382
Public Health	0573
Radiology	0574
Recreation	0575
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Toxicology	0383
Home Economics	0386

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Radiation	0754
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Acoustics	0986
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Atmospheric Science	0608
Atomic	0748
Electronics and Electricity	0607
Elementary Particles and High Energy	0798
Fluid and Plasma	0759
Molecular	0609
Nuclear	0610
Optics	0752
Radiation	0756
Solid State	0611
Statistics	0463

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Aerospace	0538
Agricultural	0539
Automotive	0540
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Chemical	0542
Civil	0543
Electronics and Electrical	0544
Heat and Thermodynamics	0348
Hydraulic	0545
Industrial	0546
Marine	0547
Materials Science	0794
Mechanical	0548
Metallurgy	0743
Mining	0551
Nuclear	0552
Packaging	0549
Petroleum	0765
Sanitary and Municipal	0554
System Science	0790
Geotechnology	0428
Operations Research	0796
Plastics Technology	0795
Textile Technology	0994

PSYCHOLOGY

General	0621
Behavioral	0384
Clinical	0622
Developmental	0620
Experimental	0623
Industrial	0624
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UNCERTAINTY ANALYSIS IN NONPOINT SOURCE WATER QUALITY MANAGEMENT

BY

JEANNE S. YULIANTI

A Thesis/Practicum submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

ABSTRACT

Managing nonpoint source pollution from agricultural land requires the control of erosion that results from rainfall-runoff conditions in a watershed. This in turn requires an agricultural management policy and the promotion of suitable agricultural practices that are aimed at keeping the sediment entering a stream within established limits. Computer models are available that can produce an optimum set of management practices for given input conditions of topography, weather conditions, crop yield, crop prices, and allowable sediment load. The problem is that several input conditions are random variables which makes it uncertain what the "best" set of management practices is.

The objective of this study is to identify robust sets of management practices in the sense that they minimize the adverse consequences of failure to meet the optimum farm revenue or failure to meet the accepted erosion standards. Three critical issues are addressed. They are: 1) the identification of management policies that are robust to uncertainty in the input parameters; 2) the identification of input parameters that are significant for the modelling of erosion and sedimentation, as well as for making effective management decisions; and 3) the identification of management practices that are robust to uncertainty in the input parameters. The research results are demonstrated for the Highland Silver Lake Watershed in Illinois.

The Sediment Economic simulation and optimization model (SEDEC) was extended to estimate the erosion and sedimentation and to determine the optimum set of management practices for a given realization of the set of stochastic input parameters. Repeating this for a large number of realizations generated by computer simulation produced the required data base for the uncertainty analysis.

Monte Carlo Simulation is used to evaluate the sensitivity of management policies to uncertainty in the input parameters. Three different management policies, the Least Cost policy, the Erosion Standard policy and the Erosion Tax policy are examined. It is shown that the Least Cost policy, which deals with the watershed as a whole, is the most robust management policy. The Erosion Tax and Erosion Standard policies, which are based on limiting erosion at individual farms, are less robust.

However, for a very restricted sediment constraint, the three policies are not much different in terms of robustness.

A Modified Generalized Sensitivity Analysis is used to identify the important parameters in the linked process of water quality simulation and optimization for sediment control. Seventy input parameters are considered uncertain. They are rainfall erosivity, crop prices, and yield under different field conditions. It is shown that the rainfall erosivity factor *R*, and the prices of corn and soybeans are important parameters in the SEDEC model. The importance of the crop yield parameters for the model results depends on the management policy. For the Least Cost policy, crop yield is not very influential. For the Erosion Standard policy, which deals with individual farms, crop yields are influential parameters. For the Erosion Tax policy, crop yields are influential parameters when dealing with individual farms. Crop yields, however, are not influential when dealing with the entire watershed.

Regret and Robustness Analyses are used to identify management practices that are likely to be appropriate for future conditions that can be expected to differ from past conditions. The Regret and Robustness Analyses lead to different "best" management practices dependent on whether regret is expressed in terms of revenue or sediment or erosion. Together, however, the analyses identify a small number of management options from which a "best" choice can be made. For the entire watershed, three robust sets of management practices are identified using the Regret and Robustness Analyses. For individual farms, one or two choices of management practice are identified for each LMU. The final choice can be left to the decision maker.

Dedicated To:

Santoso Suryono, Geert Iravati,

Iskandar Djati Utomo, Ira, and Yoanne

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CONTENTS

List of Tables

List of Figures

Appendix

INTRODUCTION 1

1.1 The Problem 1

1.2 How to Address the Problem 1
- 1.2.1 Simulation and Optimization Models 3
- 1.2.2 The Role of Water Quality Policies 3
- 1.2.3 Uncertainty Analyses 4

1.3 The Research Contribution 5
- 1.3.1 The Methodologies 5
- 1.3.2 Thesis Outline 7

LITERATURE REVIEW 8

2.1 Nonpoint Source Water Quality Management 8
- 2.1.1 Introduction 8
- 2.1.2 The Basic Erosion and Sedimentation Process 9
  - 2.1.2.1 The Process 9
  - 2.1.2.2 The Literature 10
    - 2.1.2.2.1 The Basic Erosion Process 10
    - 2.1.2.2.2 Sediment Delivery 13
- 2.1.3 Nonpoint Source Simulation Models 18
  - 2.1.3.1 Model Structure and Type 18
  - 2.1.3.2 The Models 20
    - 2.1.3.2.1 CREAMS 20
    - 2.1.3.2.2 ANSWERS 22
    - 2.1.3.2.3 EPIC 23
    - 2.1.3.2.4 SWRRB 24
    - 2.1.3.2.5 AGNPS 24
    - 2.1.3.2.6 Comparisons of Nonpoint Source Simulation Models 26
- 2.1.4 Nonpoint Source Optimization Models 27
  - 2.1.4.1 Optimization Models that Use Simulation Models. 28
  - 2.1.4.2 An Integrated Simulation and Optimization Model 30
- 2.1.5 Parameter Estimation 34
- 2.1.6 Nonpoint Source Water Quality Management Policies 36

2.2 Uncertainty Analysis in Nonpoint Source Water Quality Management 43
- 2.2.1 Types of Uncertainty 43

2.2.2 Uncertainty in the Model Parameters (Type II Uncertainty) 44
    2.2.2.1 Sensitivity Analysis 45
    2.2.2.2 First Order Analysis 46
    2.2.2.3 Monte Carlo Simulation 47
    2.2.2.4 Comparative Studies 49
2.2.3 Generalized Sensitivity Analysis 51
2.2.4 Regret and Robustness Analyses 53

SEDIMENT ECONOMIC MODEL (SEDEC) 58

3.1 Introduction 58

3.2 The Organization of Land Management Units (LMUs) and Transects 60

3.3 The Soil Economics (SOILEC) Module 60
3.3.1 The Universal Soil Loss Equation (USLE) 61
3.3.2 The Relationship between Crop Yields and Soil Loss 61
3.3.3 The Relationship between Cost and Soil Loss 63
3.3.4 The Discounted Net Returns 63
3.3.5 The SOILEC Module Output 64

3.4 The Sediment-Path Generator (S-PGEN) Module 65
3.4.1 The Sediment Delivery Ratio (SDR) 65
3.4.2 The S-PGEN Module Output 67

3.5 The Optimizer (OPT) Module 68
3.5.1 The OPT Module Output 69

3.6 The Dynamic Program Solution (DPSOLVE) Module 70

METHODS OF ANALYZING UNCERTAINTY 77

4.1 Monte Carlo Simulation 77
4.1.1 Determining the Sensitivity of the Three Management Policies 78
4.1.2 The Number of Simulations 79

4.2 Generalized Sensitivity Analysis 79
4.2.1 Original Development 79
    4.2.1.1 Classification Algorithm 80
    4.2.1.2 Statistical Analysis 80
4.2.2 The Modified Generalized Sensitivity Analysis for Linked Simulation and Optimization Models 81
4.2.3 The Modified Generalized Sensitivity Analysis for Nonpoint Source Water Quality Management 82

4.3 Regret and Robustness Analyses 83
4.3.1 Regret Analysis 84

4.3.1.1 Regret Analysis based on the Entire Watershed 84
4.3.1.2 Regret Analysis based on the Farm Unit 88
4.3.2 Robustness Analysis based on Probability 92
4.3.2.1 Robustness Analysis based on the Entire Watershed 92
4.3.2.2 Robustness Analysis based on the Farm Unit 93

CASE STUDY - DESCRIPTION 105

5.1 Description of the Study Area 105
5.1.1 Selection 105
5.1.2 Data and Assumptions used in Modelling 106
5.1.2.1 Agricultural Management 106
5.1.2.1.1 Crop Rotation 106
5.1.2.1.2 Tillage Systems 106
5.1.2.1.3 Effect of Tillage on Erosion 107
5.1.2.2 Available Data for the SEDEC Model 108
5.1.2.2.1 Rainfall Erosivity Factor 108
5.1.2.2.2 Soil Formations 108
5.1.2.2.3 The Cropping and Management Factors 109
5.1.2.2.4 The Soil Erodibility Factor 109
5.1.2.2.5 Crop Yield 109
5.1.2.2.6 Crop Prices and Cost of Management 110
5.1.2.3 Planning Horizon and Discount Rate 110
5.1.3 Stochastic Analysis of the Data 110
5.1.3.1 Stochastic Input Parameters 111
5.1.3.2 Correlation of Input Data 112

5.2 Description of the Application of the Methods of Analysis .... .113
5.2.1 Management Decisions 113
5.2.1.1 Management Policies 113
5.2.1.2 Pollution Constraints 114
5.2.2 Optimum Management for Deterministic Input 114
5.2.2.1 Least Cost Policy 114
5.2.2.2 Erosion Tax Policy 115
5.2.2.3 Erosion Standard Policy 115
5.2.3 Sensitivity of Management Policies 116
5.2.3.1 Parameter Uncertainty 116
5.2.3.2 Monte Carlo Simulation 116
5.2.3.2.1 Required Number of Monte Carlo Simulations 117
5.2.3.2.2 Output of Monte Carlo Simulations 117
5.2.4 Parameter Identification 117
5.2.4.1 Modified Generalized Sensitivity Analysis 117
5.2.5 Regret and Robustness Analyses 119

CASE STUDY - RESULTS 133

6.1 Optimum Management for Deterministic Input 133
6.1.1 Cost-Sediment Relationship under the Three Policies 138

6.2 Effect of Uncertainty on Management Decision 138
  6.2.1 Sensitivity of the Management Policies to Uncertain Input Information 138
  6.2.2 The Modified Generalized Sensitivity Analysis 141
    6.2.2.1 The Watershed Based Classification Analysis 142
    6.2.2.2 The Farm Based Classification Analysis 144
  6.2.3 Results of the Regret and Robustness Analyses 145
    6.2.3.1 Watershed Based Management Analysis 145
    6.2.3.2 Farm Based Management Analysis 148
    6.2.3.3 Summary 157
  6.2.4 Effect of the Location of an LMU on Sediment Load and Management Practice 158

SUMMARY and CONCLUSION 194

7.1 Management Policy and Practices with Deterministic Input Data 195

7.2 Management Decisions based on Uncertain Input Data 196
  7.2.1 Sensitivity of Management Policies to Uncertainty 196
  7.2.2 Modified Generalized Sensitivity Analysis 196
  7.2.3 Regret and Robustness Analyses 198
  7.2.4 The Role of Land Slope 199

7.3 Conclusions 199

REFERENCES 201

NOTATION 216

List of Tables

2.1 Water Quality Simulation Models 56
3.1 General Overview of the SEDEC Model 72
3.2 Alternative Management Practices 73
3.3 Example of the SOILEC Module Output 74
3.4 Example of the S-PGEN Module Output 75
3.5 Example of the OPT Module Output 76
3.6 Example of the DPSOLVE Module Output 76
4.1 Matrix of Management Decisions and Corresponding Total Revenue under the Watershed Based Analysis for 10 Monte Carlo Realizations 97
4.2 Matrix of Management Decisions and Corresponding Total Sediment under the Watershed Based Analysis for 10 Monte Carlo Realizations 97
4.3 Regret Matrix for Revenue under the Watershed Based Analysis for 10 Monte Carlo Realizations 98
4.4 Regret Matrix for Sediment under the Watershed Based Analysis for 10 Monte Carlo Realizations 99
4.5 Matrix of Management Decisions and Corresponding Total Revenue under the Farm Based Analysis for 10 Monte Carlo Realizations 100
4.6 Matrix of Management Decisions and Corresponding Erosion under the Farm Based Analysis for 10 Monte Carlo Realizations 100
4.7 Regret Matrix of Revenue under the Farm Based Analysis for 10 Monte Carlo Realizations 101
4.8 Regret Matrix for Erosion under the Farm Based Analysis for 10 Monte Carlo Realizations 102
4.9 Robust Matrix for Revenue under the Watershed Based Analysis for 10 Monte Carlo Realizations 103
4.10 Robust Matrix for Sediment under the Watershed Based Analysis for 10 Monte Carlo Realizations 103
4.11 Robust Matrix for Revenue under the Farm Based Analysis for 10 Monte Carlo Realizations 104
4.12 Robust Matrix for Erosion under the Farm Based Analysis for 10 Monte Carlo Realizations 104
5.1 List of Transects, LMUs, and Their Descriptions for the Highland Silver Lake Watershed 123
5.2 Alternative Management Practices for the Highland Silver Lake Watershed 124
5.3 Rainfall Erosivity, *R*, for the Highland Silver Lake Watershed 125
5.4 Soil Formations in the Highland Silver Lake Watershed 126
5.5 The *C* Average Values for Various Total Residue and Management Alternatives for Estimating Soil Erosion using the USLE for the Highland Silver Lake Watershed 127
5.6 *K* Factors and Bulk Density for Soil Horizons A and B for the Highland Silver Lake Watershed 128
5.7 Crop Yields for the Highland Silver Lake Watershed 129
5.8 Cost of Management Practices for the Highland Silver Lake Watershed 131
5.9 Correlation among Input Parameters for the Highland Silver Lake Watershed 132
6.1 Management Practices under the Least Cost Policy for an Unconstrained Sediment Load 164
6.2 Management Practices under the Least Cost Policy for a Sediment Load Limitation of 262 tons/annum 165
6.3 Management Practices Under the Least Cost Policy for a Sediment Load Limitation of 48 tons/annum 166

6.4 Management Practices Under the Erosion Tax Policy for an Erosion Tax of $2.00/ton 167
6.5 Management Practices Under the Erosion Tax Policy for an Erosion Tax of $11.00/ton 168
6.6 Management Practices Under the Erosion Standard Policy for an Erosion Standard of 3 tons/acre 169
6.7 Management Practices Under the Erosion Standard Policy for an Erosion Standard of 1 ton/acre 170
6.8 Changes in Management Practices under the Three Management Policies Relative to the Unconstrained Sediment Case 171
6.9 Sensitivity Indices for the Input Parameters under the Watershed Based Classification and the Least Cost Policy for an Unconstrained Sediment Load 172
6.10 Sensitivity Indices for the Input Parameters under the Watershed Based Classification and the Least Cost Policy for a Sediment Load Limitation of 262 tons/annum 173
6.11 Sensitivity Indices for the Input Parameters under the Watershed Based Classification and the Least Cost Policy for a Sediment Load Limitation of 48 tons/annum 174
6.12 Sensitivity Indices for the Input Parameters under the Watershed Based Classification and the Erosion Tax Policy for an Erosion Tax of $2.00/ton 175
6.13 Sensitivity Indices for the Input Parameters under the Watershed Based Classification and the Erosion Tax Policy for an Erosion Tax of $11.00/ton 176
6.14 Sensitivity Indices for the Input Parameters under the Farm Based Classification and the Erosion Standard Policy for an Erosion Standard of 3 tons/acre 177
6.15 Sensitivity Indices for the Input Parameters under the Farm Based Classification and the Erosion Standard Policy for an Erosion Standard of 1 ton/acre 178
6.16 Sensitivity Indices for the Input Parameters under the Farm Based Classification and the Erosion Tax Policy for an Erosion Tax of $2.00/ton 179
6.17 Sensitivity Indices for the Input Parameters under the Farm Based Classification and the Erosion Tax Policy for an Erosion Tax of $11.00/ton 180
6.18 Summary of Regret and Robustness Analyses under the Watershed Based Analysis 181
6.19 Alternative Robust Sets of Management Practices under the Watershed Based Analysis 182
6.20 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $\text{LMU}_{1\,2}$, $\text{LMU}_{3\,2}$, $\text{LMU}_{9\,3}$, and $\text{LMU}_{16\,2}$ 183
6.21 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $\text{LMU}_{2\,1}$, $\text{LMU}_{5\,2}$, $\text{LMU}_{6\,2}$, $\text{LMU}_{7\,1}$, $\text{LMU}_{8\,1}$, and $\text{LMU}_{9\,1}$ 184
6.22 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $\text{LMU}_{4\,1}$, $\text{LMU}_{5\,1}$, and $\text{LMU}_{6\,1}$ 185
6.23 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $\text{LMU}_{8\,3}$ 186
6.24 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $\text{LMU}_{11\,1}$ 187
6.25 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $\text{LMU}_{11\,2}$, $\text{LMU}_{13\,1}$, $\text{LMU}_{14\,1}$, $\text{LMU}_{14\,2}$, and $\text{LMU}_{16\,3}$ 188

6.26 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{12\,1}$ 189
6.27 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{12\,2}$ 190
6.28 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{13\,2}$, $LMU_{14\,3}$, and $LMU_{15\,2}$ 191
6.29 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{13\,3}$ 192
6.30 Summary of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{15\,1}$ 193

List of Figures

3.1 Schematic of LMUs and Transects 71
4.1 Cummulative Distribution Functions for the Behaviour and the Non-Behaviour Categories for a Significant Parameter X 95
4.2 Cummulative Distribution Functions for the Behaviour and the Non-Behaviour Categories for a Non-Significant Parameter X 95
4.3 Modified Generalized Sensitivity Analysis 96
5.1 Log-Normal Probability Plot of Rainfall Erosivity for the Highland Silver Lake Watershed Based on Annual Rainfall Erosivity (Wu, 1986) 121
5.2 An Example of the Relationship between the Corn Yield and Soil Depth for Soil Formation Sable 68A1 122
6.1 Trade-off between Total Sediment and Total Cost for the Deterministic Input under the Three Management Policies 160
6.2 The 5th and the 95th Percentile Confidence Limits of the Total Cost under Various Sediment Loads for the Three Management Policies 161
6.3 The CDFs of the Total Cost for a Total Sediment Load of 262 tons/annum under the Three Management Policies 162
6.4 The CDFs of the Total Cost for a Total Sediment Load of 48 tons/annum under the Three Management Policies 163

Appendix

A.1 Results of Regret and Robustness Analyses under the Watershed Based Analysis A-1

A.2 Results of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{1\,2}$, $LMU_{3\,2}$, $LMU_{9\,3}$, and $LMU_{16\,2}$ A-6

A.3 Results of Regret and Robustness Analyses under the Farm Based Classification for $LMU_{2\,1}$, $LMU_{5\,2}$, $LMU_{6\,2}$, $LMU_{7\,1}$, $LMU_{8\,1}$, and $LMU_{9\,1}$ A-11

A.4 Results of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{4\,1}$, $LMU_{5\,1}$, and $LMU_{6\,1}$ A-16

A.5 Results of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{8\,3}$ A-21

A.6 Results of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{11\,1}$ A-26

A.7 Results of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{11\,2}$, $LMU_{13\,1}$, $LMU_{14\,1}$, $LMU_{14\,2}$, and $LMU_{16\,3}$ A-31

A.8 Results of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{12\,1}$ A-36

A.9 Results of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{12\,2}$ A-41

A.10 Results of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{13\,2}$, $LMU_{14\,3}$, and $LMU_{15\,2}$ A-46

A.11 Results of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{13\,3}$ A-51

A.12 Results of Regret and Robustness Analyses under the Farm Based Analysis for $LMU_{15\,1}$ A-56

CHAPTER 1

INTRODUCTION

1.1 The Problem

Nonpoint source water pollution, especially from agricultural land, has long been a problem (He et al., 1993; Milon, 1988). It has produced among other things reservoir siltation, increased turbidity in streams, reduced channel capacity, reduced crop production, and increased nitrate concentrations. Millions of dollars have been spent on reducing nonpoint source pollution, yet much remains to be done (Milon, 1988). Erosion is considered to be the largest contributor to nonpoint source pollution because of the sediment load it imposes on the streams and because of the chemicals that are attached to the soil particles. Reducing erosion is therefore an effective way of reducing siltation, turbidity, and chemical pollution. Although erosion occurs as a natural process, the amount of erosion can be greatly reduced or increased by human activities. This study focuses primarily on erosion control as a means of nonpoint source pollution management. The goal is to obtain an optimal management solution for reducing erosion and sedimentation. Such optimal solutions have been obtained in the past from linked simulation and optimization models. However, the uncertainty inherent in natural processes, and therefore in many of the data entered in the models, leads to the question: How reliable are the management decisions that are based on such input data? To obtain the "best" management solution for reducing erosion and sedimentation, it is important to incorporate in the decision the uncertainty of the input parameters of the model. This study aims at developing useful approaches to dealing with uncertainty in nonpoint source water quality management.

1.2 How to Address the Problem

There are two ways of reducing nonpoint source pollution by controlling erosion. The first is by building control structures that prevent eroded soil from entering streams. The second is by better land management practices. In general, there are three categories of structural controls: conveyance structures, energy dissipation structures, and sediment retention structures. Conveyance structures, such as drainage canals, are built to intercept and to deflect runoff from vulnerable terrain and to transport the water without sedimentation or additional erosion. Energy dissipation structures, such as silt fences, are built to reduce flow velocities thereby reducing downstream sedimentation. Sediment retention structures, such as sediment traps, are built to collect sediment as it enters the stream. These structural controls reduce the sediment load on the stream but do not prevent erosion. The problems created by erosion are therefore only partially solved. Much land may be left gullied and scarred. Since erosion causes a loss of top soil, crop production may be decreased. To offset this, more chemical fertilizer is required which increases production costs and which may increase chemical pollution. Moreover, control structures are usually only a temporary solution. For these reasons structural control is not given consideration in this research.

Erosion control by land management aims at increasing the ability of the land to resist erosion. Available management practices are crop rotation, improved tillage systems, and mechanical runoff control. Crop rotation is used to manage the land cover. On land with dense vegetation the plants dissipate much of the rainfall energy before the raindrops reach the soil. A crop that leaves large amounts of plant residue also reduces erosion. Also important are the tillage systems which are the techniques that farmers employ to prepare a field for crop planting and weed control. Proper tillage techniques from the viewpoint of erosion control result in a rough soil surface and the retention of a substantial amount of crop residue at or near the soil surface. The crop residue and soil roughness reduce raindrop impact and runoff, resulting in more water infiltration and less soil erosion. At the same time, soil roughness and crop residue protect the soil from wind erosion. Mechanical runoff control is used to reduce the flow velocity especially in steeply sloping lands. It is accomplished by modifying the land slope, by increasing surface roughness, or by contour cultivation.

With point source pollution (e.g., from industries) the pollution load can be controlled by restricting the entrance of pollutants at the source. Nonpoint source pollution control, on the other hand, requires the management of agricultural practice in the entire part of the watershed that is under cultivation. Nonpoint source pollution control therefore raises the question of what is the best land management practice. This study assumes that it is the practice that results in optimal farm revenue while meeting the stream water quality constraints imposed on the stream. A simulation model is required to identify the set of management practices that meet water quality constraint imposed on the stream. An optimization model is required to obtain the particular management practice that produces optimal farm revenue. This implies that the appropriate management solution of nonpoint source pollution is to be based on the results obtained from linking simulation and optimization models.

1.2.1 Simulation and Optimization Models

Simulation models describe the physical process of erosion and sedimentation for a particular watershed. They are capable of estimating the erosion and sedimentation resulting from various management practices but generally do not indicate what management practices are best. Determining the optimum management practice requires an optimization model. Such a model identifies the optimal solution, in this case the management practice that leads to meeting stated water quality criteria for a stream while maximizing expected farm revenue.

1.2.2 The Role of Water Quality Policies

There are several types of management policies, e.g., standard regulations, targeted regulations or incentives such as subsidies and effluent charges. With each policy one can determine the "best" set of management practices for farms in a watershed. In this thesis optimum management decisions are developed for three different management policies, the Least Cost policy, the Erosion Standard policy, and the Erosion Tax policy. The type of policy that is best depends on considerations such as resulting water quality, cost-effectiveness, certainty of system outcome, fairness, administrative cost, and ease of implementation. The resulting water quality and cost-effectiveness are important factors in the attractiveness of the policy. Their values can be obtained from the simulation and optimization models for each management policy considered and their results can be compared. These results are usually based on a set of deterministic input data. In reality the model inputs (i.e., climatic data, soil properties, and prices) are stochastic in nature or not accurately known. It is therefore important to analyze the effect of this uncertainty on the results of the management policies.

1.2.3 Uncertainty Analyses

Uncertainty in water quality modelling can be classified into three categories: uncertainty in the appropriate model structure, uncertainty in numerical values of the model parameters, and uncertainty associated with predictions of future behaviour of the system resulting from natural variability. Uncertainty in the model structure occurs because of the difficulty of adequately representing the natural physical process. The understanding of the physical process is often incomplete and its complexity necessitates simplification in the model construction. To date rather sophisticated water quality models have been developed that represent the hydrologic processes and the transport of pollutants adequately for the purpose of a study like this. While researchers have compared different models in an effort to reduce uncertainty in the model structure, no attempt is made in this study to compare different models. Instead a particular model is chosen because it is flexible. This research focuses on the second type of uncertainty, uncertainty in the numerical values of the input parameters.

Water quality models contain many parameters required to describe the physical processes involved in the simulation. Some are much more variable than others. This means that many observations must be available to determine the magnitude of these parameters adequately. Not all, however, have a strong effect on the model output. An important part of this research is therefore the identification of the important parameters that must be included in the model given the available information. Much research has been focused on parameter uncertainty in point source water quality models, but few studies have been conducted in the area of uncertainty of nonpoint source water quality simulation and optimization models. This is the topic of the present research.

The uncertainty in the results of a given water quality management policy tends to affect the success of that policy since it may affect the degree of cooperation with the policy that one may expect. For this reason, it is important to choose a robust management policy, that is, a management policy that results in a small variability in the model output even when the variability in system input is large. When Miltz et al. (1988) compared three management policies for nonpoint source water quality management, they did not include in their study the important aspect of uncertainty. The present study addresses it specifically.

1.3 The Research Contribution

This research aims at answering the following three questions:

1. To what degree are different management policies sensitive to uncertainty in the input parameters?
2. Which parameters are important for determining the nonpoint source management solution?
3. Which set of management practices are robust to uncertainty in the input parameters?

Four approaches are used to address these questions, Monte Carlo Simulation, Generalized Sensitivity Analysis, Regret Analysis, and Robustness Analysis. They are developed for sediment management of agricultural land using the Sediment Economic simulation and optimization (SEDEC) model. The approaches for addressing the three major research questions are demonstrated for the Highland Silver Lake Watershed, in Illinois.

1.3.1 The Methodologies

Monte Carlo Simulation is used to evaluate the sensitivity of management policies to uncertain model input. Three management policies are analyzed, the Least Cost policy, the Erosion Standard policy, and the Erosion Tax policy. The Least Cost policy minimizes the total cost while meeting established sediment criteria at the end point of a given watershed. The Erosion Tax policy minimizes total cost while imposing tax charges on each farm for any amount of erosion greater than the allowable erosion rate. The Erosion Standard policy minimizes total cost while meeting a limitation on erosion from each field.

A Modified Generalized Sensitivity Analysis is used to identify which parameters are important in the linked process of water quality simulation and optimization for nonpoint source pollution control. The analysis consists of three components, a Monte Carlo Simulation, the development of a classification algorithm to separate the output into different categories as explained below, and a statistical analysis of the parameters in the different categories. Monte Carlo Simulation is used to generate many sets of model outcomes for generated values of input parameters. The classification algorithm separates the Monte Carlo output into two categories. Parameter values which produced model output that is within a reasonable range of an observation or some specified value are put in a category called the Behaviour category. Otherwise, the parameter values are put in another category called the Non-Behaviour category. An empirical probability distribution is developed for each of the stochastic input parameters in both categories. The difference between the two distributions is then analyzed statistically to determine whether a parameter is important in the sense of being influential for model outcome. This is done by comparing the cummulative distribution functions for the parameter values in the two categories. One expects large differences to be associated with the more important parameters.

The last two methods, Regret Analysis and Robustness Analysis, are used to evaluate the management practices that are robust to uncertainty in the model input. The goal is to obtain a set of management practices or model results which are likely to be acceptable for future conditions. Lack of information about the true input parameters may result in a discrepancy of the model output from the true values. The actual outcome will in general not match the optimum solution indicated by the model in terms of net farm return or in terms of meeting the sedimentation specification. Regret is used as a measure of the magnitude of such discrepancies. Robustness is used as a measure that indicates with what frequency a certain level of management performance is reached. It indicates how sensitive the management practices are to uncertainty in the input parameters. Management practices that are less sensitive to input parameters are more robust.

The management practices that are analyzed consist of a combination of five crop rotations, three tillage systems, and two mechanical runoff controls. These are analyzed in terms of their sensitivity to the changes in the model input, i.e., rainfall erosivity, crop yields and crop prices.

1.3.2 Thesis Outline

The second chapter presents a review of the literature on the management of nonpoint source pollution and various approaches to uncertainty analysis. The description of the linked simulation-optimization model used in this study is presented in Chapter 3. The methodology is presented in Chapter 4. The application of these approaches to a case study based on the Highland Silver Lake Watershed in Illinois is presented in Chapter 5. The results of the application are presented in Chapter 6, and the conclusions and the recommendations are given in Chapter 7.

CHAPTER 2

LITERATURE REVIEW

Two important components of the research described in this thesis are the management of nonpoint source pollution and the effect of uncertainty on arriving at appropriate management decisions. This chapter reviews in two parts the literature on these two components. The first part reviews the literature on the management of nonpoint source pollution. It includes a brief description of the basic erosion and sedimentation process, various relevant simulation and optimization models, some techniques of parameter estimation, and various water quality management policies. The second part reviews techniques used in uncertainty analysis including First Order Error Analysis (FOEA), Sensitivity Analysis, Monte Carlo Simulation, Regret Analysis, and Robustness Analysis.

2.1 Nonpoint Source Water Quality Management

2.1.1 Introduction

Section 2.1 reviews the literature related to a number of questions. How do erosion and sedimentation occur? Which factors can be managed to reduce erosion and sedimentation? How does one select the best simulation model for a particular watershed? How does one obtain the optimal solution for reducing erosion and sedimentation? How does one obtain a unique set of parameter values for use in a simulation or optimization model? How does one manage a watershed in such a way that the goal of a specified water quality can be obtained? The research on these questions discussed in this section assumes the input data to be known or selected. In other words, the situation to be analyzed is assumed to be deterministic. This means that, strictly speaking, the solution is valid only for the particular set of input data used. Non-deterministic analyses are discussed in Section 2.2.

Managing nonpoint source water quality pollution requires an understanding of the physical process of pollution transport, so that one is able to identify those factors that can be managed to control pollution at minimum cost. Therefore, the next section (2.1.2) presents the literature on the erosion and sedimentation process itself. This section also discusses the techniques that relate the amount of sediment in the main water courses to factors that can and to some that cannot be managed. To determine the effect of the sediment load on the water quality in a stream one needs a computer model that simulates the physical process of pollutant transport. Section 2.1.3 discusses the various simulation models described in the literature. To obtain the best solution simulation is not enough; one needs an optimization model. Such models are discussed in the next section, Section 2.1.4. All simulation and optimization models contain parameters that reflect the pertinent characteristics of the particular watershed to be modelled. The estimation and calibration of these parameters present many difficulties. The literature on parameter estimation is reviewed in Section 2.1.5. Nonpoint source pollution control requires the management of agricultural practice of the entire watershed that is under cultivation. Optimum control therefore aims at an optimal set of management practices for the entire watershed. This means aiming for optimal revenue from each field while fulfilling instream water quality constraints. A general management policy is required to attain appropriate management practices. The sixth section, Section 2.1.6, reviews the management policies described in the literature.

2.1.2 The Basic Erosion and Sedimentation Process

2.1.2.1 The Process

While erosion of the land surface can be caused by wind or by water, this study deals only with erosion caused by water since that is the primary process causing agricultural nonpoint source pollution. The soil erosion process can be divided into two parts, soil particle detachment by rainfall (interill erosion) and soil particle detachment by flowing water (rill erosion). Rain may detach a soil particle so that it can be transported but erosion occurs only if there is enough energy to actually transport the loosened soil particles. Both processes, loosening and transport, depend on the rainfall-runoff characteristics and the soil resistance to erosion. Therefore, there are two important parameters in the erosion process, the rainfall intensity, and the ability of the land to resist erosion. These two parameters depend on four factors: climate (in particular, precipitation), topography (slope and length of slope), soil properties (soil composition, permeability, and erodibility), and land cover. The rainfall intensity determines the force of the raindrops or the rainfall energy. The runoff produced by the rainfall is the overland flow or the surface runoff, i.e., the part of rainfall which is not absorbed by the soil through infiltration. Soil erodibility and land cover determine the ability of the land to resist erosion. Topography and land cover combined with the runoff determine the transport capacity. A dense vegetation dissipates some of the rainfall energy and therefore reduces erosion. These four factors are the basic parameters in an erosion simulation model.

Once the surface erosion is estimated, the question is how much of the sediment ends up in the water-body. This is expressed as the sediment delivery ratio. The following two sections review the literature on the estimation of erosion and sediment delivery ratio.

2.1.2.2 The Literature

2.1.2.2.1 The Basic Erosion Process. The basic erosion process can be expressed by the Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1978). It is a well-known equation to estimate erosion from upland fields. The equation was developed from experimental field observations gathered by the Agricultural Research Service of the U. S. Department of Agriculture (USDA). The USLE is expressed in the following form:

$$A = R*LS*K*C*P \qquad (2.1)$$

where: A = annual soil erosion loss [tons/ha];
R = rainfall-runoff factor or the annual rainfall erosivity factor [MJ-mm/ha-hour];
LS = length and steepness of slope factor;
K = soil erodibility factor [ton-ha-hour/ha-MJ-mm];
C = cropping and management factor which is determined by the crop rotation and the tillage system; and
P = conservation practices factor which is determined by the mechanical control practices such as strip cropping and terracing.

The USLE estimates the erosion process caused by the force of water that displaces and transports soil particles. Climate is expressed through R, topography is expressed through LS, soil properties are expressed through K, and land cover is expressed through C and P.

The rainfall-runoff factor R represents the erosive force of the rainfall and the erosive force of runoff from thaw or snowmelt. The R factor combines total energy and peak intensity which together represent particle detachment and transport capacity. Wischmeier (1976) developed an iso-erodent map for the United States (in Wischmeier and Smith, 1978). The R-value described by this map represents the rainfall erosivity, not the erosive forces of runoff from thaw or snowmelt. Using this map, the rainfall erosivity can be estimated by linear interpolation between iso-erodent contours. A procedure to calculate R for those locations where thaw or snowmelt occurs and for those locations not included in the map, is presented in Wischmeier and Smith (1978). A conversion of the USLE in SI units has been derived by Foster et al. (1981a).

The slope factor LS represents the erosive potential of a particular combination of slope length and slope steepness. Slope length and steepness are determined from the natural flow patterns in the watershed. If the slope varies along the path of the water, the calculation can be performed for each part or an average slope can be assumed.

The soil erodibility factor K reflects that different soils erode at different rates because of variability in soil properties such as soil texture, structure, organic matter content, and soil depth. The value of K for a specific soil type can be obtained from the state offices of the Soil Conservation Service. For a given soil type, the value of K can also be determined using the soil erodibility nomograph in Wischmeier and Smith (1978).

The cropping and management factor C represents the reduction in soil erosion resulting from growing a crop as compared with leaving the land fallow. The reduction depends on the type of crop grown, cropping system, tillage systems, yield and residue management practices. Cropping and tillage systems influence erosion potential by the degree to which the soil surface is kept rough or covered with crop residue and vegetation. A denser crop cover or more protective tillage will reduce soil erosion. Timing is another critical factor in determining the C values. It is important that farm management aims at having a dense crop during the period in which high erosive rainfall may occur since C values range from a high of 1.0 for continuous fallow to a low of 0.003 for excellent grass cover.

The conservation practices factor P represents the reduction in soil erosion resulting from the use of soil conservation practices as compared with so called vertical cultivation which is cultivation without regard for the slope of the land. Conservation practices considered are contour cultivation, contour strip cropping, and terracing.

Other relationships that describe the erosion process were developed earlier by a number of researchers, Meyer and Wischmeier (1969); Onstad and Foster, 1975; Foster et al. (1977a; and 1977b); Foster et al. (1981b); and William and Berndt (1977). The following is a list of these erosion equations in chronological order.

1. Meyer and Wischmeier (1969) derived a relationship that describes detachment of the soil particle as a function of rainfall intensity:

$$DR = CF*RI^2 \tag{2.2}$$

where: DR = rainfall detachment rate [kg/min];
CF = coefficient represent soil formation; and
RI = rainfall intensity [mm/min].

2. Foster et al. (1977a) derived a relationship that describes detachment of the soil particle as a function of overland flow:

$$DF = 6.83*C*K*S*Q \tag{2.3}$$

where: DF = overland flow detachment rate [kg/min];
K, C = values used in the USLE ;
S = slope steepness ; and
Q = overland flow rate [m^3/min-m].

3. Foster et al. (1977b; and 1981) described the interill and rill detachment as follows:

Interill detachment:

$$DL_i = 0.00457*EI*(s+0.014)*K*C*P*(\sigma_p/V_\mu) \tag{2.4}$$

Rill detachment:

$$DL_r = 6860*\zeta*V_u*\sigma_p^{1/3}*(x/22.1)^{m-1}*si^2*K*C*P*(\sigma_p/V_u) \tag{2.5}$$

where: DL_i = interill detachment rate [g/s-m^2];
DL_r = rill detachment rate [g/s-m^2];
EI = rainfall erosivity factor [MJ-mm/ha-hour];

ζ = slope length exponent for rill erosion;
si = sine of the slope angle;
K, C, P = values used in the USLE;
σ_p = peak runoff rate [m^3/s-m^2]; and
V_u = runoff volume [m^3/m^2].

The USLE has been used by several researchers (Eleveld et al., 1983; Kramer et al., 1984; Haith and Merrill, 1987; and Jones et al., 1990). These studies showed that the USLE gives a good representation of the erosion process. Eleveld et al. (1983) used the USLE without any modification, while Haith and Merrill (1987) made modifications to the coefficient values to suit specific watersheds which had different parameter values than those given in the USLE guide (Wischmeier and Smith, 1978). Haith and Merrill (1987) modified the USLE coefficient and estimated the erosion using the following equation:

$$TE_{kt} = 0.132 * R_t * (LS)_k * K_k * P_k * (AR)_k \tag{2.6}$$

where: TE_{kt} = total erosion from source area k in day t [Mg];
R, LS, K, P = values used in the USLE; and
AR = area of the watershed [ha].

2.1.2.2.2 Sediment Delivery. There are two ways of calculating the sediment delivery to the stream system: 1) using the sediment delivery ratio, and 2) using the transport capacity to the stream. The sediment delivery ratio is a ratio that corresponds to the portion of erosion that is transported to the water-body as sediment. The transport capacity is the potential transport of sediment entering the water-body. The sediment delivery estimation can be basically a black box procedure or it can be based on watershed characteristics. With the blackbox concept, the sediment delivery ratio is related to lumped characteristics of individual fields and the water-body or on lumped characteristics of the entire watershed and the water-body. Examples of blackbox estimation of sediment delivery ratio are found in Roehl (1962); Beer (1966); Onishi (1973); Seitz et al. (1975); and Wade and Heady (1977). The advantage of this approach is that it is simple and that not many data for the watershed are required. The disadvantage is that it is only applicable for a particular watershed as is shown in the studies of

Roehl (1962) and Beer (1966). A list of sediment delivery ratio or transport capacity equations based on the blackbox concept follows.

1. Roehl (1962) related the sediment delivery ratio to the watershed size. He determined the sediment delivery ratio based on a comparison of the sediment deposition in a reservoir and the sheet erosion upland of the reservoir for 15 reservoirs in the Piedmont region of the Carolinas and Georgia. He used statistical analysis to derive the relationship between the watershed size and the delivery ratio. He found for the sediment delivery ratio and the watershed area the following logarithmic relationship (see also, Novotny and Chesters, 1981):

$$\log SDR = 3.59253 - 0.23043 \log AR + 0.51022 \log RE/L - 2.78594 \log BR \tag{2.7}$$

where: SDR = sediment delivery ratio;
AR = watershed area [km^2];
RE/L = relief length ratio, the ratio of elevation difference between watershed divide and outlet to watershed length; and
BR = bifurcation ratio, the ratio of number of streams of any given order to the number in the next-higher order.

2. A similar study was carried out by Beer (1966) for 24 reservoirs and watersheds in Iowa and Missouri. However, Beer found that for his case study, the relationship between the drainage area and the delivery ratio was statistically not significant.

3. Three researchers based the sediment delivery ratio on the location of the sediment source relative to the stream. Onishi (1973) related the sediment delivery ratio to the field elevation. Seitz et al. (1975) related the sediment delivery ratio to the distance between the field and the reservoir, and Walter and Black (1988) related the sediment delivery ratio to the distance from the edge of the field to the stream edge. Walter and Black (1988) used data from the Upper Mississippi River Basin Study to demonstrate that:

$$SDR = 0.89 * LX^{0.2} \tag{2.8}$$

where: SDR = sediment delivery ratio; and
LX = distance of the field edge from the stream edge [length].

They found that this relationship performed well for the Upper Mississippi River Basin. No further study was carried out using this relationship.

4. Wade and Heady (1977) assumed the sediment delivery ratio to be a fixed proportion of the total gross soil loss from all sources within each production area. Bagnold (1966) related the transport capacity to the characteristic of the soil particle, while Yalin (1963); Foster and Meyer (1975); Novotny (1980); and Novotny and Chesters (1981) related the transport capacity to the flow rate.

5. Novotny (1980); and Novotny and Chesters (1981) claimed that the sediment delivery ratio is proportional to the overland flow:

$$SDR \sim q^{\beta} \tag{2.9}$$

where: SDR = sediment delivery ratio;
q = overland flow [m3/s]; and
β = coefficient ranging from 1.2 to 1.5.

The sediment delivery ratio or the transport capacity can also be related to specific characteristics of the watershed, such as topography, land use, and soil properties. Examples of estimating transport capacity from watershed characteristics are found in Yalin (1963); Bagnold (1966); Onstad and Foster (1975); Foster and Meyer (1975); Foster (1986); William and Berndt (1977); Clarke (1983); Clarke and Waldo (1986); and Dickinson et al. (1990). The advantage of this procedure is that the results are to a greater degree applicable to other watersheds. The disadvantage is that it requires more field data. Some of the relationships that are used in the various simulation models described in the literature are listed below.

1. Yalin (1963) related the transport capacity to land slope and flow rate. This relationship was modified by Beasly et al.(1980) as follows:

$$T_F = 146 * S * Q^{0.5} \qquad for \quad Q \leq 0.046\ m^2/\text{min} \tag{2.10}$$

$$T_F = 14600 * S * Q^2 \qquad for \quad Q > 0.046\ m^2/\text{min} \tag{2.11}$$

where: T_F = sediment transport capacity [kg/min-m];
S = slope steepness; and
Q = overland flow [m^3/min-m].

2. Bagnold (1966) included in the transport capacity formula the fall velocity of the soil particle:

$$T_F = \eta * k * \tau * U_c^2 / U_{ss} \tag{2.12}$$

where: T_F = sediment transport capacity [kg/s-m];
η = effective transport factor;
k = transport capacity factor;
τ = flow shear stress [$\mathrm{kg/m^2}$];
U_c = average channel velocity [m/s]; and
U_{ss} = particle fall velocity [m/s].

This equation can be used for simulation models that calculate the sediment delivery separately for different parts of the watershed, called cells. The sediment from overland flow in a cell enters the "channel" within a cell and is routed from cell to cell via "channels".

3. Foster and Meyer (1975); and Foster (1986) related the transport capacity to the stream flow:

$$\frac{DT}{DC} + \frac{q_s}{T_c} = 1 \tag{2.13}$$

where: DT = detachment or deposition by flow [g/s-m^2] ;
DC = detachment capacity of flow [g/s-m^2];
q_s = sediment load of flow [g/s-m] ; and
T_c = transport capacity of flow [g/s-m] .

4. Clarke (1983); and Clarke and Waldo (1986) considered the relationship between the erosion upland and the deposition at the lower land adjacent to it. They described the sediment delivery ratio as follows:

$$SDR_{j-1} = \frac{C_{j-1}}{C_j} * \frac{S_{j-1}}{S_j} * \frac{P_{j-1}}{P_j} \tag{2.14}$$

where: SDR_{j-1} = sediment delivery ratio for the jth-1 land segment;
C_{j-1} = cropping and management factor in the USLE for the jth-1 land segment;
S_{j-1} = slope of the jth-1 land segment;
P_{j-1} = conservation practices factor in the USLE for the jth-1 land segment;
j = upland segment; and
j-1 = low-land segment.

The soil eroded from upland is not entirely transported to the water-body. Some of the eroded soil will be deposited along the path. This reduction in the total eroded soil that reaches the water-body depends on the transport capacity. If the transport capacity is decreased, part of the soil is deposited. Clarke (1983); and Clarke and Waldo (1986) evaluated the sediment delivery ratio using two principles. The first principle is that as sediment moves downslope from one land segment to the other the transport capacity is reduced proportional to the reduction in the cropping and management factor *C*, the conservation practices factor *P*, and the length and steepness of slope factor *LS* in the USLE. The second principle is that the deposition along the path is inversely proportional to any reduction in transport capacity, i.e., deposition increased as transport capacity decreased.

5. Dickinson et al. (1990) related the sediment delivery ratio to the land slope and surface roughness:

$$SDR_s = a(\frac{1}{ns} * S^{1/2} * \frac{Hs}{Ls}) \tag{2.15}$$

where: SDR = sediment delivery ratio;
ns = seasonal surface roughness;
S = land slope;
Hs = seasonal hydrologic coefficient;
Ls = seasonal overland flow path; and
a = calibrated watershed parameters.

A third approach was sometimes used by researchers. They estimated the total sediment that ends up in the water body in terms of the total sediment yield.

1. Onstad and Foster (1975) estimated the erosion based on the USLE and described the sediment yield as follows:

$$Y = (0.49*EI+3.42*V_u*\sigma_p^{0.333})*LS*K*C*P \tag{2.16}$$

where: Y = sediment yield [tons];
EI = rainfall erosivity in the USLE [MJ-mm/ha-hour];
V_u = runoff volume [m^3/m^2];
σ_p = peak runoff rate [$m^3/s\text{-}m^2$)]; and
LS, K, C, P = values used in the USLE.

2. A similar study was carried out by William and Berndt (1977). They estimated the sediment yield based on the USLE and described the sediment yield as:

$$Y = 11.8 * (V_u * \sigma_p)^{0.56} * LS * K * C * P \tag{2.17}$$

where: Y = sediment yield [tons] ;
V_u = storm runoff volume [m^3];
σ_p = peak runoff rate [m^3/s]; and
LS, K, C, P = values used in the USLE.

2.1.3 Nonpoint Source Simulation Models

2.1.3.1 Model Structure and Type

All simulation models considered here have three components, the hydrologic component, the erosion component, and the chemical component. In some models two or all three components are combined. The hydrologic component simulates the rainfall-runoff process. The erosion component uses the results of the hydrologic component as input and proceeds to simulate the erosion and sediment transport process. The hydrologic and the erosion components provide the necessary input to the chemical component which simulates the transport of pollutants.

Using the simulation models requires three steps. The first step is entering the input data. The second step is performing the simulation process, which represents the physical process. The last step is preparing the output in the desired form.

Simulation models can be classified as lumped models or as distributed models. A lumped model treats a watershed as a single unit, with parameters that are assumed to be valid for the entire watershed. A distributed model distinguishes various parts of the watershed, called cells, that may have different characteristics for topography, soil properties, and land use, and that therefore require separate parameter estimates.

An example of a lumped model is the EPIC, Erosion-Productivity Impact Calculator (Williams et al., 1982) model. The advantage of a lumped model is that it is simple. Once it is calibrated and verified, it can be used to determine the output using various sets of hydrological data as input. The disadvantage of a lumped model is that any changes in the watershed requires a new estimate of the coefficient and parameter values. Another disadvantage of this model type is that it requires a fairly intensive and reliable record of field data for calibration. Such a record is seldom available.

Examples of a distributed model are the ANSWERS, Areal Nonpoint Source Watershed Environment Response Simulation (Beasly et al., 1980; and 1982), the SEDIMOT, SEdimentology by DIstributed MOdel Treatment (Wilson et al., 1984a; and Wilson et al., 1984b), and the AGNPS, AGricultural Nonpoint Source Pollution (Young et al., 1987) models. The advantage of a distributed model is that not only the output of the entire watershed can be obtained, but also the output from each cell. Another advantage is that any changes in each cell can easily be incorporated. The disadvantage of the distributed models is that they require a large computer memory. The physical process of pollutant movement is simulated in each cell and between the cells. Therefore a distributed model is much more complex than a lumped model.

Simulation models can also be classified as event models or as continuous models. An event model simulates runoff and pollution transport based on an individual storm event, such as a large storm. A continuous model simulates runoff and pollution transport continuously over a long period.

Examples of event models are the ANSWERS and AGNPS models. The advantage of event models is that they require less hydrological data, and therefore less computer memory is used. The disadvantage of event models are that they require reliable information on initial or antecedent soil moisture conditions.

Examples of continuous models are the CREAMS, Chemicals, Runoff, and Erosion from Agricultural Management Systems (Knisel and Nicks, 1980; and Knisel, 1980), the GWLF, Generalized Watershed Loading Functions (Haith and Shoemaker, 1987; and Haith et al. 1992), and the HSPF, Hydrologic Simulation Program Fortran (Donigian et al., 1984a) models. The advantage of continuous models is that they simulate long term runoff and therefore the initial soil moisture conditions need not to be known accurately. In addition, a long record of output can be generated and statistical techniques can be applied to derive the relationship between input and output. The disadvantage of continuous models is that they require a long simulation time and a large computer memory. This disadvantage may lead to a limitation of the analysis of alternative management proposals.

2.1.3.2 The Models

Table 2.1 lists the names of nonpoint source water quality simulation models reviewed in this research, the model components, and their classifications. Only nonpoint source water quality simulation models that include erosion or sediment components, which is the interest of this study, are listed in Table 2.1. Other nonpoint source water quality simulation models have been reviewed and are available upon request. The first column lists the name of the models, this is followed by the components in the model, i.e., runoff, erosion, and chemicals. The last two columns list their classifications (i.e., distributed or lumped; continuous or event). Only the most commonly used nonpoint source water quality simulation models are reviewed here.

2.1.3.2.1 CREAMS. CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) was developed by the U.S.D.A., Agricultural Research Services. The model and the user manual are described in several USDA Conservation Research Science Reports (Knisel and Nicks, 1980; and Knisel, 1980). This model is designed for continuous simulation, but it has the capability for a single event or breakpoint rainfall simulation. CREAMS is a lumped parameter model. It is designed to simulate a field of up to forty hectares in size, however, it has been applied by Roka et al. (1990) for fields of up to several hundred hectares in size.

CREAMS consists of three components, a hydrology component, an erosion component and a chemical component. The hydrology component has two options for simulating runoff. In the first option, runoff is estimated using daily rainfall data and the modified Soil Conservation Services (SCS)

Curve Number method (Soil Conservation Service, 1972). In the second option, runoff is estimated using hourly or breakpoint rainfall data and the Green and Ampt infiltration equation (Knisel, 1980). The erosion component simulates erosion and sediment yield. The estimation of the erosion is based on a modified USLE (Foster et al., 1977b). The estimation of transport capacity is based on the Yalin equation (1963). The chemical component simulates the transformation and the movement of nutrient and pesticides using the daily flow and the soil loss. The estimation of the chemical pollutant is based on the approach presented in Leonard and Wauchope (1980).

CREAMS is validated during the initial model development and each of the components is evaluated separately (Knisel, 1980). Experience shows that the hydrologic component generally predicts average annual runoff well. Knisel observed that the erosion component predicts erosion better than the USLE described in Section 2.1.2.2.1.

Other researchers have also calibrated and validated CREAMS. A brief review of their conclusions follows. Rudra et al. (1985) calibrated and validated CREAMS for a case study in Southern Ontario. During the calibration period, two parameters, the soil erodibility and the soil hydraulic conductivity, were modified. They found that the model predicted the runoff well but not the erosion. They concluded that the errors resulted from the soil detachment equation. Subsequently, they recalibrated the erosivity factor in this equation, with much better results for the calibration period. However, the model did not consistently produce good erosion and sedimentation results during the validation period.

Morgan (1985) concluded that CREAMS predicted long-term annual soil erosion well for a watershed in the United Kingdom. However, he observed that CREAMS poorly predicted the runoff on a daily or monthly basis. Bengtson and Carter (1985) found that CREAMS under-estimated the monthly runoff during the cooler season and over-predicted the runoff during the warmer season for a flat land of the Lower Mississippi Valley. They also found that CREAMS under-predicted soil erosion by 61%. Lorber and Mulkey (1982) also concluded that CREAMS under-estimated erosion for lands in the Mississippi River Delta. Ewing (1989) investigated the performance of CREAMS for a watershed in Central Illinois. He concluded that the model is fairly accurate in predicting annual runoff and sediment delivery. He found that some discrepancies are caused by the assumption of uniform field characteristics. The model performs better if the variability of a field is incorporated. He suggested that the variability in the field characteristic be included by applying the weighting averages for parameter values. Roka et al. (1990) found that CREAMS performs well in predicting the runoff for the Upper Eastern Shore in the mid-Atlantic Coastal Plain of Maryland. The model also resulted in a reasonable prediction of the erosion, although the prediction tended to exceed the observed erosion.

The literature reviewed shows that CREAMS is the most widely used simulation model for nonpoint source pollution. In general, CREAMS performs well in predicting annual average runoff. However, in many cases, CREAMS poorly predicts the erosion and sedimentation.

2.1.3.2.2 ANSWERS. ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation) was developed by Beasly et al. (1980). ANSWERS is a distributed parameter model and is designed for a single event or a breakpoint rainfall model. The model is designed to simulate watersheds of up to 10,000 hectares in area. The runoff component simulates the overland flow, subsurface and channel flow. It uses infiltration estimates based on Holtan's equation (1961). The sediment yield component consists of two parts, the soil detachment by raindrop and overland flow and the sediment transport. The soil detachment by raindrop and overland flow is based on the work of Meyer and Wischmeier (1969); and Foster (1976). The sediment transport is based on a modified Yalin equation (1963).

Lovejoy et al. (1985) used ANSWERS to simulate sediment yield in their analysis of the cost-effectiveness of four erosion reduction programs in the Finley Creek Watershed, Indiana. The study area is about 1900 hectares. They did not evaluate the performance of the model in predicting amounts of sediment, but used it to estimate the sediment reduction for four different programs. The authors found that ANSWERS is useful for this type of problem.

Wu et al. (1993) evaluated the performance of ANSWERS models in predicting runoff and erosion for three watersheds. These watersheds have a total area of 0.55 hectares, 1.1 hectares, and 28 hectares. They compared the simulation results with the field data and observed that ANSWERS performed well in predicting runoff, however, the model under-estimated the sediment yield especially for large storm events. Rudra et al. (1993) applied ANSWERS to study the effect of observed rainfall rates in predicting runoff and erosion. In the calibration procedure, the soil erodibility, and the crop management parameter were adjusted. The results showed that the ANSWERS output was quite sensitive to the rainfall time step selected. They found that peak runoff and sediment yield are more sensitive to the rainfall time step than the maximum erosion rate and total runoff. Bingner et al. (1992) evaluated the performance of ANSWERS in predicting erosion for three Mississippi watersheds for different storm sizes. They compared the results to field data and showed that the model under-predicted runoff and sediment by more than 60%, especially for flat land. For terraced land, the model over-predicted runoff by 90% and sediment by 68%. This occurred for all sizes of storm.

2.1.3.2.3 EPIC. EPIC (Erosion-Productivity Impact Calculator) was developed by Williams et al. (1982) to determine relationships between erosion and soil productivity for the entire U.S. This model simulates erosion caused by water and also erosion caused by wind. EPIC is designed for a storm event model for small watersheds of approximately one hectare. As a lumped parameter model, it assumes the watershed to be a single unit, with a homogenous topography and soil type. The sediment yield is estimated based on the Onstad and Foster (1975) modification of the USLE.

Edwards et al. (1994) used EPIC to evaluate runoff and sediment, nitrogen, and phosphorus loads from four pasture fields in northwestern Arkansas. Their goal was to obtain an effective management tool that reduces sediment and nutrients in runoff from fertilized pasture areas. The watershed areas that they examined ranged from 0.57 hectares to 1.46 hectares. The EPIC model was used without calibration, and the model results were compared to the observed data. They found that the model performed well for predicting runoff, sediment, phosphorus and organic-nitrogen based on a storm event or on the annual storm. However, the model did not predict the runoff transport of nitrate well for either type of storm. EPIC was evaluated by comparing it with other simulation models such as CREAMS, ANSWERS, AGNPS, and SWRRB in predicting runoff and erosion in watersheds in Mississippi by Bingner et al. (1989; and 1992). They concluded, that contrary to the findings of Edward et al. (1994) EPIC performs well in the estimation of runoff, but not for sediment.

2.1.3.2.4 SWRRB. SWRRB (Simulator for Water Resources in Rural Basin) is designed as a storm event model (Williams et al., 1985). It is a lumped model, in which the watershed is based on one slope length. However, there are options to refine the model by dividing the watershed into subwatersheds that have homogeneous field characteristics. This model is designed to simulate a field of up to 10,000 hectares in area. The runoff is estimated using the modified SCS Curve Number method (Soil Conservation Service, 1972). The sediment is estimated based on a modified USLE (Williams and Berndt, 1977). SWRRB was developed to determine the effect of management decisions on runoff and sediment yield for ungaged rural river basins throughout the U.S. The model does not allow the user to update the parameters. However, much of the data have been incorporated in predefined data sets for various regions of the U.S. and soil types. The performance of the model was evaluated by Bingner et al. (1989; and 1992) for predicting runoff and erosion for three watersheds in Mississippi. They concluded that SWRRB performed well in the estimation of runoff and sediment for upland and flat land, but not for terraced land.

2.1.3.2.5 AGNPS. AGNPS (AGricultural Nonpoint Source Pollution) is a distributed parameter model based on a single event storm (Young et al., 1987). It is designed to simulate a field of up to 20,000 hectares in area. The estimation of the runoff is based on the SCS Curve Number method (Soil Conservation Service, 1972). The sediment components of the model simulate erosion and sediment transport. The estimation of the erosion is based on a modified USLE (Wischmeier and Smith, 1978), and the estimation of the sediment transport is based on a modified form of Bagnold's equation (1966).

AGNPS was applied for different watersheds by Prato and Shi (1990); Kozloff et al. (1992); and He et al. (1993). Other researchers also compared the performance of AGNPS to other simulation models in predicting runoff and sediment (Bingner et al., 1989; and 1992; and Wu et al., 1993). In evaluating the effectiveness of management practices, Prato and Shi (1990); and Kozloff et al. (1992) related the water quality aspect to economics, i.e., cost-effectiveness, while He et al. (1993) focused on the water quality aspect only.

Prato and Shi (1990) applied AGNPS for evaluating the effectiveness and efficiency of three management practices used to control erosion in the Tom Bell Watershed, Idaho. This watershed is about 4500 hectares in area. An economic model called Erosion Planning (EROPLAN) was added to estimate the annual net returns for each management practice. Using the AGNPS and EROPLAN models, Prato and Shi identified the most effective and efficient management practice.

He et al. (1993) used AGNPS to analyze management practices that are effective for reducing runoff, sediment, nitrogen, and phosphorus entering the Cass River in the Saginaw Bay Watershed, Michigan. The area of the watershed is 841 square miles. GRASS (Geographic Resource Analysis Support System) was used to generate input parameter value (land use types, topography, watershed boundaries, and soil types) for the AGNPS model. He et al. found that conservation tillage reduces soil erosion, but not the nitrogen and phosphorus load. The best way of reducing sediment yield and nutrient load for this particular watershed was a combination of contour farming and crop residue cover. Using GRASS and AGNPS the investigators identified the most critically eroded field in the watershed. However, the accuracy of the AGNPS simulation output of sediment and chemicals was not verified since no field data were available for comparison.

Bingner et al. (1989) evaluated the performance of AGNPS in predicting runoff and sediment for three watersheds in the state of Mississippi ranging from 1.1 hectares to 15.6 hectares in area. They compared the simulation results to the observed data. They found that the model performed well for predicting runoff. For predicting sediment, the model appeared to be well suited for flat land but not for upland or terraced land. For the same study area, Bingner et al. (1992) evaluated the performance of AGNPS in predicting runoff and sediment for different storm sizes. They found that AGNPS is well suited to flat land areas of uniform slope. However, for all storm sizes AGNPS under-predicted the runoff by an average of 28% and the sediment yield by an average of 52% for an upland watershed. Wu et al. (1993) also evaluated the performance of AGNPS in predicting runoff and erosion. Their study areas were 1.1 hectares and 28 hectares in area. They compared the simulation results with the field data and found that AGNPS performed well in predicting runoff, however, the model under-estimated the sediment yield especially for large storm events.

No validation of the AGNPS model for a large watershed was found in the reviewed literature. Bingner et al. (1989; and 1992) and Wu et al. (1993) compared the simulation results to the field data, but they used small watersheds. The studies by Prato and Shi (1990); and He et al. (1993) showed the ability of AGNPS to analyze the effectiveness of management practices for large watersheds. However, not much information has been obtained on the accuracy of the model in predicting erosion or the transport of chemical pollutants.

2.1.3.2.6 Comparisons of Nonpoint Source Simulation Models. Bingner et al. (1989) compared the SWRRB, CREAMS, EPIC, AGNPS, and ANSWERS models as to their performance in predicting runoff and erosion for three watersheds in Mississippi. The three watershed areas range from 1.1 hectares to 15.6 hectares. Two types of rainfall conditions were analyzed, an annual average storm and a single storm event. Bingner et al. modified ANSWERS and AGNPS for the annual average storm. The results of each simulation model were compared to the observed data. They concluded that none of the five models predicted runoff and sediment well for every case. However, for most of the cases, CREAMS, SWRRB, and AGNPS predicted runoff and sediment better than the other models. EPIC predicted the runoff well but not the sediment yield. In most cases, ANSWERS did not perform as well as the other models. A similar study for the three watersheds was carried out by Bingner et al. (1992). In this study they focused on the performance of the five models in predicting runoff and erosion for different storm size ranging in increments of 15 mm. Bingner et al. (1992) categorized the three watersheds in terms of their slope as a flat watershed, an upland watershed, or a terraced watershed. Then they compared the model results to the measured data. They found that there is a linear relationship between runoff and rainfall, and between erosion and rainfall, using all five models. However, the slope of the regression line was significantly different from the one for the observed data. The results show that for flatland, SWRRB and AGNPS performed better than other models. CREAMS and SWRRB predict runoff and sediment yields within 20% from the measured data for an upland watershed, and none of the models performed well for a terraced watershed. The authors also showed that error increases with the size of the storms.

Wu et al. (1993) compared the performance of three nonpoint simulation models, ANSWERS, AGNPS, and CREAMS, in predicting runoff and sediment yield for three experimental watersheds in Ohio. Their study areas were 0.55 hectares, 1.1 hectares, and 28 hectares. Thirty rainfall events were analyzed. The model results were compared to the measured data. They found that in all cases the runoff resulting from the models was close to the measured data, however, none of the three models performed well in predicting sediment yield. In most cases the models under-estimated sediment yield for large storms. For the case study, ANSWERS performed better than CREAMS or AGNPS.

It may be concluded that the three comparative studies of simulation models show that, in general, the models perform well for predicting runoff. However, the ability to predict sediment is questionable. It was observed that in most cases large discrepancies occurred because a model was used beyond its limitation, or because some modifications were made to match the study (e.g., an event model may be adjusted for use in continuous cases).

2.1.4 Nonpoint Source Optimization Models

Some optimization models use the results of existing simulation models (Crowder et al., 1985a; and Crowder et al., 1985b), and others integrate the physical and economic aspects of a system in a single optimization model (Braden et al. 1985). Optimization models that use the results of existing simulation models have a limited choice of alternatives in determining the optimum solution, since they are limited to the set of alternatives generated by the simulation model. This set may or may not include the true optimum (Braden et al., 1989a; and Wu et al., 1989). It is therefore important to integrate the economic analysis with the simulation model. Examples of optimization models found in the literature are described below.

2.1.4.1 Optimization Models that Use Simulation Models.

Crowder et al. (1985a) presented a study that incorporates economics directly into environmental planning. The study aimed at determining the most economical management practice that would meet the water quality criteria for a stream that receives runoff from a dairy farm in Pensylvania. The CREAMS model was used to estimate the sediment yield resulting from the dairy farm, and the relationship between dairy waste and runoff pollution was incorporated into a linear programming optimization model that minimized the cost of management subject to instream water quality constraints.

Crowder and Young (1987) extended the work by Crowder et al. (1985a) to include controlling nutrient losses from agricultural land. The CREAMS model was used to evaluate the sediment yield and nutrient load from agricultural land for eleven sets of management practices. These sets consist of combinations of vegetative cover, tillage system, sodded waterways, and terracing. CREAMS was linked to a linear programming optimization model to estimate the most cost-effective management practice that meets the instream sediment and nutrient load criteria. The results showed that no-till planting, reduced tillage, and sodded waterways are more cost-effective for controlling sediment and nutrient load than other practices. Terracing and permanent vegetative cover were found to be high cost management practices. Crowder and Young (1987) determined the most cost-effective management practices for controlling sediment and surface runoff losses of nutrients. However, these practices may increase nitrate losses in deep percolation, and considering the control of nitrate may lead to a different cost-effective solution.

Crowder et al. (1989) linked the CREAMS simulation model with a linear programming optimization model to evaluate the effect of watershed slopes and soil types on the cost-effectiveness of pollutant control in a study area located in the Upper Eastern Shore in the mid-Atlantic Coastal Plain of Maryland. Two slopes in each of two soil type categories were considered, a 3.5 % and a 7.5 % slope. The CREAMS model was used to predict the sediment yield and the nitrate load. The economic model was based on profit maximization. The results showed that slope and soil type influence the cost-effectiveness of the optimal management solution, that is a trade-off exists between reducing sediment or nitrate percolation losses and cost. The reason is that different soil types would have a different crop yield as well as different erosion resistance. Crop yield would directly influence the revenue or cost, while erosion would dictate the sediment load. The authors did not discuss whether the location of such lands with respect to the stream would affect the cost-effectiveness of the optimal management solution.

Jones et al. (1990) determined the management practice that maximizes profit while meeting erosion criteria for an irregularly sloped watershed in eastern Nebraska. The trade-off between profit and erosion control was also analyzed to determine the most profitable management practice. The USLE was used in the evaluation of the erosion. The parameter *LS* in the USLE is usually estimated from the average length of the land and the average steepness of slope. For a long watershed, however, the erosion calculated on the basis of an average *LS* may not be appropriate; i.e., the erosion will be under-estimated for convex slopes and will be over-estimated for concave slopes. Considering this problem, the authors divided their study area, which has a total length of 400 feet, into six land slope segments ranging from 40 to 102 feet. The slope gradients range from 2% to 8%. Management practices consist of combinations of four crops, three tillage systems and two cultivation practices for each land segment. The results showed that trade-offs exist between erosion control and profits for management practices in each of the land segments. By analyzing these trade-offs, the authors could select the management practice for each land segment that met the erosion criteria and minimized cost. The results also showed that changes in tillage system is more effective in reducing erosion compared to introducing crop rotation. However, if erosion must be further restricted, alfalfa should be grown. The authors suggested that in order to reduce the sediment entering the stream, alfalfa should be planted starting with the lower land adjacent to the stream and proceeding to the upland for stricter controls. They found that by dividing the land into segments, a more economic solution could be obtained.

Kozloff et al. (1992) used the AGNPS simulation model in a study of targeting cropland improvement programs aimed at reducing sediment yields and nutrient losses in a watershed in Minnesota. The results of the simulation model were combined with economic data to evaluate the cost-effective solution with respect to sediment reduction. The authors found that cost-effectiveness increases with information about the contribution of the land to downstream sediment yield.

In a recent study, Ejaz and Peralta (1995) linked a simulation model to a non-linear optimization model to determine the optimal management solution for controlling both agricultural pollutants and domestic waste water emissions, subject to downstream water quality criteria. The results of the simulation model were compared with the QUAL2E simulation model results. The authors found that the results were similar, but that their model was simpler and faster. The results of the optimization model showed that the upstream inflow rates from agricultural land and the constraints on downstream total nitrogen and nitrite concentrations significantly influenced the cost-effective solution. It is therefore important to include the uncertainty of the input parameters in determining the cost-effective solution.

2.1.4.2 An Integrated Simulation and Optimization Model

The integrated simulation and optimization model, SEDEC (Sediment Economics), was developed by Braden et al. (1984). This model can be used to solve sediment control problems and at the same time minimize the cost of land management. It integrates economic and physical factors in the control of agricultural nonpoint pollution. The erosion is estimated based on the USLE, while the total sediment entering the stream is calculated based on the sediment delivery equation (Clarke, 1983). Dynamic programming is used to determine the optimal land management solution.

In terms of physical factors, this model simulates the movement and the delivery of sediment (i.e., erosion and deposition) from agricultural land to a water-body. In the SEDEC model, a watershed is divided into land management units based on the uniformity of the slope and available management practices. This model also considers the importance of the soil type in each land management unit. The importance of slope and soil type in determining the cost-effective management practices has been demonstrated in previous studies (Crowder et al., 1989; Jones et al., 1990; and Kozloff et al., 1992). The model can be used to identify the sets of management practices in each plot of land that meet the erosion criteria at each plot or that meet the sediment criteria for the entire watershed while minimizing cost. Each management practice is composed of a combination of crop rotation, tillage system, and mechanical control. Since this model was extended to analyze the effects of uncertainty in this thesis, a detailed description of it is presented in Chapter 3.

Wu et al. (1989) investigated whether the optimal management practices based on an average annual storm differed from those based on single storm events. They use the SEDEC model to evaluate the best management practices to control sediment using these two types of storm for a case study in the Highland Silver Lake Watershed in Illinois. The annual average storm is based on 25 years of rainfall data. Five storm events were analyzed, storms with return periods of 2 years, 5 years, 20 years, 50 years, and 100 years, respectively. Sixty management practices, consisting of a combination of 5 crop rotations, 3 tillage systems, and 4 mechanical controls, were analyzed for each field. The authors first compared the revenue associated with optimal management practices for each of the storms that would reduce sediment yield by 20% and 40% with the revenue without a sediment limitation. Then, using the optimal management practices based on the annual average storm for the 20% and 40% sediment reduction, they estimated the sediment yield for the event storms. Finally, using the optimal management practices based on the event storms for the 20% and 40% sediment reduction, they estimated the sediment yield for the annual average storms. The results showed that, as sediment is more restricted, the optimum choice of crop is shifted to meadow or permanent alfalfa, the tillage system changes from chisel-in-Fall to no-till and the mechanical control changes from contour to terrace. The authors observed that the cost-effective land management practices are different for storm events than for the average annual storm. They concluded that the cost of reducing the sediment load under event storms is larger than the cost based on the average annual storm.

Braden et al. (1989a) studied the importance of the sediment delivery ratio in determining a cost-effective solution to meet sediment criteria for the Long Creek Watershed in Illinois. Four methods for estimating the sediment delivery ratio were analyzed. These four methods are the Clarke and Waldo method (1986), the fixed coefficient method, the single coefficient method, and the Walter and Black method (1988). Clarke and Waldo estimated the delivery ratio based on the changes in the slope and management practices between fields as the sediment moves downstream. The single coefficient method is based on a single value of the delivery ratio for the entire watershed, i.e., the ratio of total erosion to total sedimentation. The fixed coefficient method is based on a fixed delivery ratio for each field, which is the ratio of the sediment from each field to the erosion on that field, i.e., the matrix of fixed delivery coefficients for the entire watershed. The Walter and Black method estimated the sediment delivery ratio based on the distance from the edge of the field to the stream edge. The results show that for the same percent reduction in sediment yield, the cost based on the latter three methods is higher compared with the cost based on the Clarke and Waldo method. The authors found that to meet the sediment load, the four methods lead to different best management practices. The results also showed the effect of location for those fields that are to be improved. The Clarke and Waldo and the Walter and Black methods showed that the lands to be improved are located mostly close to the stream, while the other two methods showed locations of lands to be improved spread over the entire watershed. The authors found that the sediment delivery ratio is important in determining the cost-effective solution. Furthermore, they observed that applying the correct management practices in critically eroded fields greatly reduces sedimentation with much less inconvenience than occurs when farmers are required to reduce erosion below a certain erosion level on all land or on all highly erodible land, as is the current practice.

Braden et al. (1989b) extended the SEDEC model to determine consequences for fish habitat suitability of the management practices in a study area in Berrien County, Michigan. The habitat suitability index (HSI) model was used in addition to the SEDEC model. They investigated the effect of pesticide runoff on chemical habitat suitability and the effect of sediment runoff, in terms of changes in the percentage of fine particles in the stream, on the suitability of the physical habitat. A suitability measure between 0 and 1 was developed, in which 0 represents an unsuitable habitat and 1 represents an optimal habitat. Three of these suitability levels were investigated. The authors evaluated the cost of achieving the three suitability criteria and related it to the probability of exceedance of the suitability levels. They found that changes in tillage systems were required to achieve a maximum 25% probability of exceedance for all of the three suitability level criteria. As the target probability of exceedance is increased, changes in crop rotation to alfalfa are required. Although no-till systems would give better results in terms of sediment control, they would result in higher concentrations of pesticides which in turn adversely affect habitat suitability.

Bouzaher et al. (1990) compared the advantages of the dynamic programming optimization model in SEDEC with two linear programming codes for determining cost-effective management practices for meeting sediment criteria. Two study sites were used, the Long Creek Watershed and the Highland Silver Lake Watershed in Illinois. The two linear programming codes are the LINDO and APEX computer software. Four crop rotations, three tillage systems and three mechanical control practices were included in the analysis. The authors compared the performance of the linear programming codes also in terms of their computational time. They found that the dynamic programming model is faster than the other codes without a difference in the accuracy. Some of the tests exceeded LINDO's capacities, while the dynamic programming in SEDEC is able to solve even larger problems.

2.1.5 Parameter Estimation

The purpose of parameter estimation or calibration is to fit the general model to the specific conditions of a particular watershed. This is done by comparing the output of the model with observed data or with what experience or insight in the phenomenon would lead one to expect. Calibration of a model with observed data requires that one measures the discrepancy between the model output and the observed data and that one attempts to choose parameter values that minimize this discrepancy.

There are in general two approaches to this problem, the deterministic approach and the stochastic approach. With the deterministic approach a single set of best parameters is determined from the available evidence. The uncertainty in the parameters may be acknowledged but plays no role in the decision making. With the stochastic approach the uncertainty in the parameters is quantified and incorporated in the construction and the use of the model.

Minimizing the discrepancy between the model output and the observations is an optimization problem involving an objective function. This can be done manually or automatically. The latter has the advantage of speed, objectivity, and accuracy and is therefore more generally used. However, unless used with judgement, it may lead to unrealistic parameter values.

A problem with finding the best choice of parameter values is that the simulation model may serve more than one purpose. Its aim may be to simulate the runoff, the sediment load to the water-body and the transport of chemical pollutants. The optimum choice of parameters for one of these outputs may not be the optimum choice for the others.

The first study on automatic calibration for hydrologic models was conducted by Dawdy and O'Donnel (1965). Their work is based on an automatic optimization approach developed by Rosenbrock (1960). Beard (1967) and DeCoursey and Snyder (1969) focused on estimating the optimal parameter values for a hydrologic model. They obtained the optimal choice of parameter values by minimizing the difference between the observed and the computed values. A more complex hydrologic model, a precursor to the HSPF model, the Stanford Watershed Model (Crawford and Linsley, 1966), incorporated automatic calibration using the least squares error criterion. While other researchers used systematic search techniques in determining the optimal parameter values, Karnopp (1963) introduced a random search technique for solving this problem.

Ibbit and O'Donnel (1971) reviewed various fitting methods in hydrologic models. They compared the performance of various techniques in obtaining the optimal set of parameter values. Seven systematic search techniques and a random search technique were analyzed. They found that the rotating coordinate technique developed by Rosenbrock (1960) was the most efficient method for calibrating the hydrologic model. The random search technique (Karnopp, 1963) was found to be more efficient than the systematic search techniques for complex problems. Ibbit and O'Donnel (1971) suggested that the results of the random search technique (Karnopp, 1963) be used as the starting point in determining the parameter values.

The studies mentioned approached parameter estimation from a mathematical rather than from a statistical point of view. The objective function is to minimize the sum of squared errors in these values. Recognizing the stochasticity of the input parameters, Box and Tiao (1973) used the Bayesian methods in parameter estimation. With Bayesian methods, a prior probability density function is assigned to the parameters to express their randomness. The available data are then used to update the probability density function and to arrive at the posterior probability density functions of the parameters. This allows the derivation of the probability density function of the model output. The variance of this function is a measure of the uncertainty in the output. Troutman (1985) discussed parameter estimation in detail using this approach. Other references to the application of Bayesian theory to parameters estimation in hydrologic models are Vicens et al. (1975); Kuczera (1983); and Edwards and Haan (1988; and 1989a). Sorooshian and Dracup (1980) also used a statistical approach to parameter estimation. They utilized the maximum likelihood theory to parameter estimation. The difference between the Bayesian theory and the maximum likelihood is that the latter does not require an assumption about the prior probability distribution of the parameter.

While many studies have been directed to parameter estimation for a single output, i.e., to simulate the runoff or to simulate the sediment load, some studies have investigated parameter estimation for multiple outputs. Box and Draper (1965); Box and Tiao (1973); and Bates and Watts (1988) estimated parameters for multi-output hydrologic models. Vladimir (1981); and Rudra et al. (1985) suggested that one calibrate the parameters in nonpoint source simulation models based on individual outputs, calibration of the runoff model first, then calibration of the sediment model and then calibration of the pollution or chemical model. They mentioned the importance of preventing the error in one model from causing large errors in the output from the other models. Leavesley et al. (1983); Edwards and Haan (1988); and Yan and Haan (1991) showed indeed, that if a model is calibrated for one output, the best parameters for that output may give poor results for other outputs. They estimated parameters for multi output systems by assigning a weighting factor for each of the outputs. Thus, they obtained a set of parameters which may not be optimal for any one output but is better overall.

2.1.6 Nonpoint Source Water Quality Management Policies

Once a suitable simulation model has been obtained and calibrated, the question becomes what management policy will best meet the goals of water quality control. This is also an optimization problem defined by an objective function, state variables, decision variables and constraints. It requires first the identification of the goals of the exercise, i.e., reducing sediment or chemical pollutants to allowable levels, or both. Such goals are usually expressed in the form of constraints placed on the feasible solutions. Next, it is necessary to define the management policies that are to be considered and the management practices that may be chosen. A management practice can be quite specific in the form of crop restrictions, allowable tillage system or degree of terracing required. The management policies can also be standard regulations regarding sediment of nutrient yield from fields, targeted regulations aimed at the most significant contributors, or incentive programs in the form of subsidies or effluent charges. In any event the objective function must be clearly defined. It is usually economic efficiency but this target may vary depending on how costs are distributed.

Kramer et al. (1984) evaluated the cost-effectiveness of three management policies, a regulatory program, soil loss taxes, and a cost-sharing program aimed at reducing sediment yield, nitrogen and phosphorus in Nansemond River and Chuckatuck Creek Watershed in Southeast Virginia. A linear programming optimization model was used in the study to maximize the net farm income for the entire watershed subject to pollution limitation. The USLE was used to estimate soil loss from each field in the watershed. A field was defined as land with the same cover and soil type. The sediment delivery ratio was based on pollutant loading indicators. Phosphorus and nitrogen were estimated based on the work of Novotny and Chesters (1981) who calculated phosphorus and nitrogen using the concept of potency factors and calculated soil loss using the USLE.

The regulatory program in Kramer was based on constraining soil, nitrogen and phosphorus loadings from each field. The soil loss tax policy was based on imposing charges on each ton of soil loss, and the cost-sharing program is based on decreasing the cost of production of crops related management practices that reduce pollution. Three regulatory alternatives were analyzed, a 25%, 50%, and 75% reduction in all three pollutants. A 50% reduction in each individual pollutant was also considered. Two levels of tax charge were included in the analysis, a $0.50 and a $1.00 tax per ton of soil loss. Three cost-sharing levels were analyzed. These were a 50%, 75%, and 100% subsidy of the cost of the changes required. The percentages of subsidy were given for all applications of best management practices except for no-till practices. For no-till practices, a flat $37.50 per hectare subsidy was assigned. The results using these policies were compared to a base case, which assumed no pollution policy. The results showed that, using a standard regulatory policy, the best management practice depends on the goal of the pollution reduction. If sediment yield is the primary goal, then the optimum management practice is different than if nutrient or phosphorus reduction is the primary goal. For the case where all pollutants were reduced uniformly, an increase in the percentage of pollutant reduction required changes in tillage systems from conventional tillage corn to no-till corn or to grass. For the 50% reduction of the pollutant individually, the same changes in tillage systems were required except for the case where only phosphorus was reduced. In reducing the phosphorus load, most of the tillage system remained conventional tillage corn. This may be because no-till systems would have increased the phosphorus load by using more pesticides. In terms of farm income, the standard regulatory policy resulted in a reduction of the total farm income. Therefore, this policy is effective in reducing pollution, but it is not cost-effective.

The soil loss tax policy was found to be the least economic policy in reducing the three pollutants in terms of farm income. Changes in tillage systems were required as pollution was restricted, i.e., requiring changes from conventional till to no-till and non-crop land. Compared to the standard regulatory policy, a $0.50 tax per ton soil loss would have resulted in the same pollution load as the 25% pollution reduction under the regulatory policy. A $1.00 tax per ton soil loss would have resulted in a reduction of the pollution load between 50% and 75% as might have been achieved under the regulatory policy. In terms of farm income, the result using a $1.00 tax is similar to a 75% pollution reduction enforced by standard regulatory policy. However, using a $0.50 tax showed a reduction of 2% in farm income compared to the case of the 75% pollution reduction under the standard regulatory policy.

The last policy, cost-sharing, was found to be the most economic policy for reducing pollution in terms of farm income. Compared to the previous two policies, the results under this policy show that income increases because farmers receive income both from agricultural production and from the government. However, it is an expensive policy for the government. Furthermore, increasing the percentages of the subsidies to 75% and 100% does not improve the pollutant load.

It is to be expected that the subsidy policy would turn out to be the best solution for farmers, since the cost in meeting the pollution criteria is shared with the government. The standard regulatory policy and the erosion tax policy are comparable in terms of farm participation in reducing pollution, i.e., the consequences of not meeting the pollution criteria are imposed at the farm level. However, the results of these two policies may differ somewhat in equity or fairness. The results of the study showed that the total farm income is similar under a $1.00 tax to the case under a standard regulatory policy requiring between 50% and 75% pollution reduction. However, the changes in the management practices indicated a significant effect of the two policies on individual farm income. Using a $1.00 tax, about 24% of the watershed used conventional tillage corn and 12% changed from crop land to grass land, while for the same pollution criteria under the standard policy only 8% of the watershed used conventional tillage corn and about 1.3% changed from crop land to grass land. The remaining portion of the watershed required a change to no-till or to other crop rotation. These results showed that under the standard regulatory policy most of the watershed was still used as crop land and therefore almost all of the individual farms were profitable. Contrarily, under the tax policy, about 25% of the watershed is highly profitable, while 12% of the watershed is not profitable. The results showed that for a field with a highly eroded soil, high tax charges will force farmers a change from cropland to grass. Under the standard regulatory policy, this highly eroded land may still be profitable in meeting the erosion criteria by changes in the tillage systems or by crop rotation.

Lovejoy et al. (1985) linked ANSWERS with an economic analysis to evaluate the effectiveness of four management policies aimed at reducing sedimentation in the Finley Creek Watershed, Indiana. The ANSWERS model was used to estimate the sediment yield. The four management policies based on voluntary subsidies programs were a non-targeted reduced tillage subsidy, a targeted reduced tillage subsidy, a targeted annual conversion subsidy, and a targeted permanent conversion subsidy program. In the first policy, the subsidy was given on a first-come first-served basis to those who changed tillage systems from a conventional tillage system to a reduce tillage system, while in the second policy the subsidy was based on the predicted sediment yield in the simulation. The third and the fourth policies were based on a restriction on the production of corn and soybeans on highly eroded soil, i.e., only 2 ha of these type of fields were allowed for the production of corn and soybeans. The latter policy differed in the payment procedure. The three former subsidy types were paid annually and the latter subsidy was paid one time only. A discount rate ranging from 2% to 10% was analyzed for an infinite number of subsidy years. Five percentages of participation of farmers in the watershed were investigated, 1%, 5%, 10%, 15%, and 100%. The results showed that, for an interest rate of 6% and participation rates of 1-15% the policy of basing subsidies on sediment yield is more cost-effective than other policies. However, for an interest rate of less than 6% or for a sediment reduction of less than 25%, a permanent conversion program was found to be more cost-effective, especially if administrative cost is included. The authors concluded that allocating scarce financial resources to those areas that produce the most sediment would be quite cost-effective. This makes sense since the sediment would be reduced directly and unnecessary changes in tillage systems from conventional to reduced tillage would be avoided.

Miltz et al. (1988) compared three management policies for managing sediment in the Highland Silver Lake Watershed, Illinois. The SEDEC model was used to estimate the soil loss and the farm revenue for each alternative management practice for each field, and the total sediment and total revenue or cost for each set of management practices for the entire watershed. The model also obtained an optimal management solution under each policy.

The three policies examined were the least cost policy, the soil erosion tax policy, and the soil erosion standard policy. The least cost policy assumed that the planner was informed of the best management practices for reducing sediment. This information was based on a cost-effective management solution for meeting the sediment criteria resulting from a simulation-optimization model. The soil loss tax policy was based on imposing charges on the per ton soil loss. The erosion standard policy was based on constraining soil loss from each field. A range of total sediment criteria from 50 tons to 350 tons at the end of the watershed was analyzed.

The relationship between the cost and total sediment load under the three policies is important information for the decision maker, since it represents the effectiveness of each policy. A policy that constantly results in a lower cost in meeting any sediment criteria would be preferable. The results show that the least cost policy is the most cost-effective solution for the range of sediment criteria considered. The erosion standard policy produces the least cost-effective solution, while the erosion tax policy is somewhere in between. However, the erosion tax policy outperforms the erosion standard policy only when the total sediment load is less than 100 tons. This result contradicts the conventional understanding of the cost-effectiveness of these two policies. The authors explained that this result may occur because there is a positive correlation between the cost of erosion control and pollution transport coefficients or the sediment delivery ratio. If the variance of the sediment delivery ratios is large relative to the variance of the discharge abatement costs, then the occurrence of such a result is more likely.

Prato and Shi (1990) evaluated the effectiveness of three pollution control strategies for Idaho's Tom Beall Watershed. The three strategies are two erosion control strategies and a riparian water pollution control strategy. Prato and Shi used the AGNPS model to calculate the erosion, the nitrogen and phosphorus loads, and the chemical oxygen demand under these three strategies. The EROPLAN model was used to calculate the net return for each management practice. Two types of storms were analyzed, the average annual storm and separate event storms. The average annual storm was used for estimating the erosion. Four storm events, with 10, 25, 50, and 100 year return periods, were used for estimating the erosion and chemical pollutant load. A 4% discount rate and a period of 20 years were used in the analysis. A total of 11 management practices were considered. These consisted of a combination of wheat-pea crop rotation, with three tillage systems, and up to four mechanical control practices. Permanent vegetative cover was also an option.

The erosion control strategies restricted the erosion rates while maximizing the annual net returns per hectare. Two erosion criteria based on the Food Security Act of 1985, namely the 1 T limit and the 1.5 T limit, were analyzed. The 1 T and a 1.5 T limits are equivalent to 11.2 tons per hectare and 16.8 tons per hectare soil eroded, respectively. The riparian strategy used good cover (i.e., grass, trees, or shrubs) on those fields adjacent to the creek and in non-cropland areas and applied a management system that maximized annual net return per hectare on the remaining fields.

The results showed that for the annual storm, the 1 T limit strategy is the most efficient strategy for reducing erosion compared to the other two strategies. The results also showed that under the 1 T limit, about 44% of the total acreage requires permanent vegetation cover, while under the 1.5 T limit and the riparian strategy the total acreage of cover are 17% and 14%, respectively. The authors did not mention whether all fields adjacent to the creek were changed to permanent vegetation under the 1 T limit strategy. If this was the case, then the better performance of the 1 T limit strategy over the other two strategies is not surprising. In terms of farm income, all three policies resulted in a decrease in farm income. In terms of erosion reduction efficiency, i.e., dollars per unit ton reduction of pollution, the 1 T limit strategy was also the most cost-effective.

For the four storm events, the results showed that the riparian strategy was the most cost-effective for reducing erosion and chemical pollution. Although this strategy outperformed the two erosion strategies, the riparian strategy was less equitable in terms of income losses, since those fields adjacent to the creek did not produce any profit, while the remaining fields remained profitable.

Jones et al. (1990) questioned the effectiveness of the erosion standard policy in meeting sediment criteria in an irregularly sloped watershed in eastern Nebraska. Under the erosion standard policy, each field was required to meet the erosion criteria. The watershed was divided into land segments based on their position from the stream. A modified USLE was used in the estimation of the erosion from each land segment. A trade-off between profit and erosion control was analyzed to determine the most profitable management practice in each land segment. The results showed that the location of the field from the stream significantly influenced the sediment load. Therefore, the erosion standard policy may not lead to an economically effective solution. The authors suggested a flexible management policy which would allow farmers to apply management practices that exceed the standard by very little. As their results showed the importance of the land location, a policy based on a reasonable approximation of the contribution of a land segment to downstream pollution may be a cost-effective solution.

Kozloff et al. (1992) investigated the cost-effectiveness of seven criteria in controlling erosion, sedimentation, and nutrient losses in a watershed in Minnesota. The seven criteria were based on the on site erosion limitation, the sediment yield and nutrient load limitation at the end of the watershed and the budget constraints. The AGNPS was used to evaluate the erosion, sediment yield, and nutrient load. An integer program was used to optimize the total sediment yield and nutrient losses at the watershed outlet subject to budget constraints. Kozloff et al. (1990) found that for this case study, the interdependency between fields in delivering sediment to the stream was small. Therefore, they assumed field independence in their analysis. They suggest some general guidelines for allocation of a limited budget for data collection and for subsidies to the farmers. They also suggested to use existing data first to identify the relative heterogeneity of the watershed with respect to productivity and erodibility characteristics, and then to obtain more data on the parameter that has the greater heterogeneity.

2.2 Uncertainty Analysis in Nonpoint Source Water Quality Management

2.2.1 Types of Uncertainty

This section reviews the research that addresses uncertainty in water quality modelling and management. Vincens et al. (1975); and Troutman (1985) classify uncertainty in the hydrology aspect of modelling into three categories, uncertainty in the model structure (Type I uncertainty), uncertainty in the model parameters (Type II uncertainty), and uncertainty resulting from natural variability (Type III uncertainty). Beck (1987) identifies four problem areas related to uncertainty in water quality modelling, uncertainty in the model structure, uncertainty in the model parameters, uncertainty associated with predictions of the future behaviour of the system, and uncertainty resulting from natural variability. Actually, the uncertainty associated with the prediction of the future behaviour of the system is a combination of uncertainty in the model structure, uncertainty in the model parameters, and natural variability. It makes sense to distinguish natural uncertainty which arises from the variability of meteorologic factors (e.g., rainfall and temperature) from uncertainty in the model and its parameters. Natural uncertainty cannot be reduced by obtaining more information while uncertainty related to model type and parameter estimation can. The distinction between model type uncertainty and parameter uncertainty is also valid because the parameter uncertainty can be quantified while the model type uncertainty cannot be expressed in a probability distribution.

Uncertainty in the model structure (Type I uncertainty) occurs because of lack of understanding of the physical process, because of necessary simplification in model structure, and because of incomplete information. Type I uncertainty can be reduced by selecting the best available model for a particular watershed. Considerable effort has been directed to developing new hydrology and water quality simulation models that reduce Type I uncertainty. The result is that these new models have become more and more complex in their attempt to represent the physical hydrologic and pollutant transport process more accurately. Few studies, however, have attempted to analyze Type I uncertainty. Ellis (1988) attempted this in a model of acid rain abatement in which he compared the performance of seven air pollution simulation models using Regret Analysis. Warwick (1989) presented an analysis of Type I uncertainty, in which he compared the performance of DO models based on an expanded Streeter-Phelps equation and on the simplified Streeter-Phelps equation in predicting the DO levels for waste load allocation. Cardwell and Ellis (1993) analyzed Type I uncertainty in an evaluation of the optimal solution of waste management in a river basin, in which they compared the performance of three water quality models using Regret Analysis. The increased complexity of the new models have raised the need for a closer examination of the input parameters with a view of determining which parameters are important and which can be omitted from the model without compromising the results. The research on choosing appropriate parameters will be discussed in Section 2.2.3. Research on choosing robust sets of management practices in view of parameter uncertainty is reviewed in Section 2.2.4.

The uncertainty in the model parameters (Type II uncertainty) has been the subject of many studies concerned with hydrologic models, e.g., Troutmant (1985); and Haan (1989), and water quality models, in particular those dealing with point source pollution, e.g., Beck (1987). Far fewer studies have concentrated on parameter uncertainty in nonpoint source pollution models. Those that have been reviewed are discussed in Section 2.2.2.

2.2.2 Uncertainty in the Model Parameters (Type II Uncertainty)

Type II uncertainty is caused by the fact that parameters must be estimated from a limited set of input data that are subject to random variability, for example, the natural climatic variability to which rainfall and temperature are subjected. In nonpoint source pollution management, three ways of analyzing this uncertainty have been commonly applied, Sensitivity Analysis, First Order Analysis, and Monte Carlo Simulation.

Sensitivity Analysis identifies the effect of the variability of the input parameters on the model output by changing each input parameter in turn and observing the effect. This technique is sometimes used to determine which parameters can be excluded from the model. First Order analysis relates the means and the variances of the model output to the means and the variances of the input parameters through simulation. Monte Carlo Simulation may be used to approximate the probability density function of the model output using generated random values of the input parameters as input. The results can be used to construct confidence limits for the model output. The research on these methods is reviewed in the three subsections that follow.

2.2.2.1 Sensitivity Analysis

Sensitivity Analysis has been used to analyze the sensitivity of the model output to changes in the input parameters. The common procedure is to vary the value of each selected parameter in turn, while other parameters are kept constant. Sensitivity Analysis has been used in hydrologic models and water quality models. Tarrer et al. (1976) applied Sensitivity Analysis to identify important input parameters in activated sludge waste-water treatment plant optimization model. They found that Sensitivity Analysis provided a good insight in which input parameters should be used to obtain a robust water treatment design. Several researchers (Gardner et al., 1980a; 1980b; and 1981; Beck, 1987; and Yeh and Tung, 1993) have shown that a traditional Sensitivity Analysis in which the sensitivity of each parameter is analyzed separately is not adequate for the determination of the source of uncertainty that affects the model output most. Milon (1987) used Sensitivity Analysis to evaluate the effect of the changes in pesticide decay rates and hydraulic conductivity on output from the Pesticide Root Zone model.

Cooper et al. (1992) used Sensitivity Analysis to evaluate the effect of changes in the input parameters in the CREAMS model on runoff, sediment load, and nutrient and phosphorus concentrations from steep slope pastures field in Scotsman Valley near Hamilton, New Zealand. They found that porosity, field capacity, hydraulic conductivity and the SCS Curve Number were the critical input parameters for the prediction of runoff, while the soil erodibility and soil loss ratio parameters were important parameters for the prediction of sediment load. Three input parameters, extraction coefficient, potentially mineralizable nitrogen, and potential nitrogen uptake parameters, were found to be critical in predicting nutrient concentrations. Two parameters, fertilizer phosphorus content and extraction coefficient parameters, were found to be moderately important in predicting phosphorus concentrations, while manure was not important.

Ejaz and Peralta (1995) used Sensitivity Analysis to evaluate the effect of upstream flow and total nitrogen limitation on the management of waste loads from domestic and nonpoint source pollution from dairy farms. The QUAL2E model and a water quality simulation model developed by Ejaz and Peralta (1995) were used to simulate BOD, DO, total nitrogen, and phosphorus concentrations. The upstream flow was varied from the deterministic flow by 10%, and the total nitrogen limitation was relaxed by up to 25%. They found that both upstream flow and the total nitrogen limitation significantly influenced the waste load allocation.

Sensitivity Analysis can be used to rank the contribution of each input parameter to the model output so as to identify input parameters that have a large influence and to eliminate those that do not. A more refined technique of accomplishing this, a Generalized Sensitivity Analysis, will be discussed in Section 2.2.3.

2.2.2.2 First Order Analysis

In First Order Analysis the uncertainty in the model input is expressed by the variance of the input parameters around their mean values. The mean and the variance of the input parameters are then used to estimate the mean and variance of the model output. Several researchers have compared the performance of First Order Analysis with Monte Carlo Simulation (Burgers and Lettenmaier, 1975; Melching, 1992; Melching and Ammangandla, 1992; and Haan et al., 1995). A review of these studies is presented in Section 2.2.2.4.

First Order Analysis was first applied by Burgers and Lettenmaier (1975) to analyze the uncertainty in the simulation model output of the DO-BOD in a stream. They mentioned that First Order Analysis gives correct results if the coefficients of variation of the uncertain parameters are small.

Burn and McBean (1986) applied chance constraint programming to optimize a water quality planning model. First Order Analysis was used to quantify the uncertainty in the input parameters. Four input parameters were considered uncertain, travel time, flow, transfer coefficients, and pollutant loading. Optimizing water quality as traditionally formulated is difficult when transfer coefficients are uncertain. For this reason, Burn and McBean modified the optimization formulation. In their modified formulation, the transfer coefficients were incorporated in the objective function and cost is included as a constraint. They applied the model in the management of two sources of waste discharge to the Speed River near Guelph. The goals were to minimize cost and maximize DO concentrations at four checkpoints downstream. The authors compared two distribution types that can be used to describe the uncertainty in the transfer coefficients, a normal distribution and a lognormal distribution. The results of the simulation model were compared to the predicted DO at four check points downstream using four probability levels. The authors concluded that lognormal distribution of the DO deficit provided a better fit.

2.2.2.3 Monte Carlo Simulation

The uncertainty in the model output caused by the uncertainty in the model input can be expressed most completely by the probability density function of the model output. This can be achieved by Monte Carlo Simulation. Monte Carlo Simulation treats the input parameters as random variables and generates a large number of sets of random values for them. The result of entering these sets in the model is a series of output values that can be used to estimate the probability density function of the model output which then can be used to derive confidence limits on the output. Monte Carlo Simulation has been applied for uncertainty analysis in hydrologic simulation models and in water quality simulation and optimization models.

Whitehead and Young (1979) applied Monte Carlo Simulation to include uncertainty in the input parameters in the Bedford water quality model to obtain probability distributions of daily DO and BOD levels in the Bedford Ouse River system in central eastern England. They compared the distributions of DO and BOD obtained by Monte Carlo Simulation to the observed distributions of DO and BOD. They found that the important input parameters differ for different rivers in the Bedford Ouse River system.

Burn and McBean (1986) employed Monte Carlo Simulation to quantify the uncertainty in flow, pollutant loading, travel time, and the reaction coefficient in a DO model based on the Streeter-Phelps equation. The optimization of the water quality as formulated by Burn and McBean (1985) concerned the waste load allocation of five point source pollutants in the Schuylkill River watershed. The goal was to determine the waste load allocation that maximized the weighted sum of the DO concentration in twelve checkpoints downstream of the source while minimizing the treatment cost. Equity constraints were added to the optimization formulation. Four options of equity level were analyzed and trade off curves between the treatment cost and the water quality were developed for each option. The results showed that the DO deficit based on the stochastic model and the Monte Carlo Simulation at the twelve checkpoints were in acceptable agreement. The maximum difference in DO deficit between the two models for the twelve checkpoints based on 90% probability of exceedance was about 9%.

Edwards and Haan (1989a; and 1989b) employed Monte Carlo Simulation to study the effect of input parameter uncertainty on the estimation of peak flows for fifteen watersheds in the Washita River basin in south central Oklahoma. Two input parameters in a rainfall-runoff model based on the SCS unit hydrograph were considered uncertain, the maximum potential soil moisture abstraction and the time to peak of the unit hydrograph. A probability distribution of the peak flow for different storm events was obtained from the 2000 Monte Carlo Simulations. The authors concluded that the flood frequency curve obtained was in agreement with the one based on observed data.

Edwards (1990) used Monte Carlo Simulations to study the effect of parameter uncertainty on estimating sediment yield for three small rangeland watersheds in Oklahoma. A Modified USLE

(MUSLE) erosion model was used to evaluate the erosion rates from the watershed. The soil erodibility factor and the cropping and conservation factor in the USLE were considered uncertain. He found that the approach can be used for estimating the range of sediment yield that may result from uncertain input parameters. The results showed that the observed sediment yield was within the 90% confidence interval of the predicted sediment yield.

Lewis et al. (1994) developed PRORIL, an erosion model that incorporates the uncertainty in the rill flow, and applied it to a field study at the University of Kentucky. Distribution functions were assigned to the rill spacing, rill flow rates, and rill flow time to express the uncertainty in the rill flow. The authors found that the erosion and sediment resulting from the model were in reasonable agreement with field data. Although this may be a promising approach, information of the rill spacing and the rill flow rates is rarely available

2.2.2.4 Comparative Studies

Burgers and Lettenmaier (1975) employed Monte Carlo Simulation to derive the probability distributions of the DO and BOD due to uncertainty in travel time, reaction coefficients and temperature in a simulation model based on Streeter-Phelps equation. They found that the temperature was the least sensitive parameter; the travel time and decay coefficient parameters were important for travel time less than the critical travel time, and the reaeration coefficient was important around the critical travel time. They then compared the results of the Monte Carlo Simulation to results from the First Order Analysis. They concluded that the agreement between the analyses was quite good. The difference in the mean value of the DO increased with travel time, however, the maximum difference was only 3%. The maximum difference in the variance of the DO was about 20%. The maximum difference in the mean of the BOD was about 23% and the maximum difference in the variance was about 20%.

Improved First Order Analysis was used by Melching (1992) to evaluate the effect of uncertainty in peak discharge estimates for the Vermilion River Watershed at Pontiac, Illinois. The performance of the improved First Order Analysis was then compared to traditional First Order Analysis and Monte Carlo Simulation. Two rainfall-runoff models were used, a lumped system model and a non-linear conceptual runoff model. Five input parameters in the rainfall-runoff model were considered uncertain. The results showed that the improved First Order Analysis is in good agreement with the Monte Carlo Simulation in predicting peak discharge over a wide range of probability of exceedance. Melching demonstrated that the improved First Order Analysis performed better than the First Order Analysis also in non-linear systems. Melching and Ammangandla (1992) applied improved First Order Analysis in an application of the Streeter-Phelps model. Different distributions for the model parameters were used such as normal, lognormal, gamma, and uniform distributions. The authors compared the performance of the First Order Analysis, the improved First Order Analysis, and the Monte Carlo Simulation in predicting the probability distribution of critical DO deficit. They found that the improved First Order Analysis produced results similar to the Monte Carlo Simulation with less computational time, while the First Order Analysis gave a reasonable agreement for the mean value of the critical DO deficit compared to the result using Monte Carlo Simulation. They compared the results to previous studies by Burges and Lettenmaier (1975) which used a normal distribution for all parameters. They concluded that the type of distribution for the parameter does not influence model output very much.

Haan et al. (1995) used the three methods, Sensitivity Analysis, First Order Analysis, and Monte Carlo Simulation, to evaluate the performance of hydrologic models in cases where limited data are available. They did this for mean monthly streamflows in the Little River Watershed in Georgia. First, the Sensitivity Analysis was used in determining which input parameters were important for the model prediction. Then, the First Order Analysis or Monte Carlo Simulation was used to determine the probability distribution of the model output. They used First Order Analysis for a single uncertain parameter, and Monte Carlo Simulation for multiple uncertain parameters. In cases where limited data are available, the authors suggested as a preliminary solution to estimate the probability density function for several potential values and to use the most likely value to obtain the best expected performance. They found that by adding more uncertain parameters, the uncertainty in the model output increased.

2.2.3 Generalized Sensitivity Analysis

An important consideration in model building and in the analysis of uncertainty in simulation models is the choice of parameters to be incorporated in the model. Many parameters are incorporated in simulation models, however, not all parameters have the same variability nor do they all have a strong effect on the model output. Ordinary sensitivity analysis can be used to judge the relative importance of the parameters qualitatively. This leaves the researcher with the question of when is a parameter important enough to include it in the model. Generalized Sensitivity Analysis was developed by Spear and Hornberger (1980) to provide a statistical basis for this decision. At the same time Generalized Sensitivity Analysis makes it possible to choose preferred values for the parameters. Beck (1987) recognized the Generalized Sensitivity Analysis as an innovative approach in the process of parameter estimation; i.e., it helps reduce the dimensionality of parameter estimation.

Generalized Sensitivity Analysis consists of three components, a Monte Carlo Simulation, a classification algorithm and a statistical analysis. The Monte Carlo Simulation is used to generate various model outcomes. A range for model output that is considered reasonable is defined. The classification algorithm categorizes the model output into two classes: if the model output is within the range considered reasonable, it is recorded in the Behaviour category, otherwise it is recorded in the Non-Behaviour category. For each of the uncertain parameters, an empirical probability distribution is developed for each of the two classes. Using a statistical test, the two distributions are then compared. If the distributions of the two classes are significantly different for a given parameter, that parameter significantly affects the model output. A detailed procedure of Generalized Sensitivity Analysis is presented in Chapter 4.

Generalized Sensitivity Analysis was first applied in the identification of important parameters in a phosphorus based model for the eutrophication in Peel Inlet II in Western Australia (Spear and Hornberger, 1980). A total of 19 input parameters were considered uncertain and randomly generated values were used as input to the simulation model. The simulation model results were compared to the field data. The classification algorithm was based on the consideration of whether or not the model results were within reasonable deviation limits from the field data. The results showed that 7 of the 19 parameters were not important for the model output. A similar classification algorithm was used by Humphries et al. (1984) in their preliminary study identifying the processes in the nitrogen cycle that are important to macroalgal growth in the Peel Inlet. They compared the parameter values obtained from the laboratory and field data to the ones estimated by Spear and Hornberger (1980). Humphries et al. found that the parameter values based on the Spear and Hornberger approach were reasonable and that they demonstrated the success of a Generalized Sensitivity Analysis approach. Hornberger and Spear (1981) extended a Generalized Sensitivity Analysis to cases where correlations exist among input data. The input parameters were transformed to reduce correlation among them. Spear and Hornberger (1983) used a Generalized Sensitivity Analysis to select the important design parameters for a waste treatment lagoon that was to maximize the probability of meeting the DO level in a river reach of the River Cam. They found that four out of thirteen parameters influenced the model output significantly. The results showed that the DO criteria could be maintained with a probability of 84%.

Hornberger et al. (1985b) applied a Generalized Sensitivity Analysis in an attempt to identify the important parameters for the rainfall-runoff model TOPMODEL (Beven and Wood, 1983) under various behaviour classifications for the Shenandoah National Park. They found that some parameters remained important under most behaviour classifications, however other parameters changed when the behaviour criteria were changed. They concluded that it is difficult to choose the appropriate parameter values for this watershed.

Lence and Takyi (1992) modified a Generalized Sensitivity Analysis for cases where simulation and optimization are linked to determine optimal water quality management strategies and where correlations among input data exist. The classification algorithm was based on a comparison with a deterministic solution of the management solution, i.e., the optimization results for the case where inputs to the simulation model were chosen, or estimated, from the history of record for the system. The technique was applied for managing dissolved oxygen on the Willamete River. They successfully identified the important parameters for the linked simulation and optimization water quality management models of this system.

Generalized Sensitivity Analysis was used in other water quality investigations (Van Straten, 1981; Halfon and Maquire, 1983; Hornberger et al., 1985a; and Jakeman et al., 1990), an activated sludge model (Sperling, 1993), and in many different problems including the dynamics of moth (Auslander, 1982) and mosquito (Eisenberg et al., 1994) populations, control engineering (Auslander et al., 1982; and Tsai and Auslander, 1988), toxicology (Spear et al., 1991), and nuclear safety (Cook and Gimblett, 1991).

2.2.4 Regret and Robustness Analyses

Regret and Robustness Analyses applied in nonpoint source pollution management identify management practices that may be expected to perform best for a range of values which the uncertain input parameters may assume. Regret measures the discrepancy between the model output or prediction and the actual outcome. Such discrepancy may be caused by uncertainty about the model or the input parameters. Robustness measures the probability that the model output or prediction remains valid within specified limits when the input parameters are stochastic.

Regret theory was described by Loomes and Sugden (1982) as an alternative theory of choice under uncertainty. Regret Analysis was applied in studies of air pollution control strategies and several studies of point source water quality management (Hashimoto et al., 1982; Ellis, 1988; Uber et al., 1991; Burn and Lence, 1992; and Cardwell and Ellis, 1993). Hashimoto et al. (1982) applied Regret and Robustness Analyses to determine the optimal solution of an expansion of a regional water supply system in southwestern Skane in Sweden, in which the future demand was considered uncertain. They defined regret as the difference between the actual costs and the costs that would be incurred with a least cost design for the actual demand conditions. The criterion of robustness is the probability that the cost of a specific system will be no greater than a certain percentage of the cost of the least cost design for the actual future demand condition. They found that the Robustness measure was more useful in situations where design costs vary widely among alternatives.

Ellis (1988) analyzed the effect of Type I uncertainty, that is, uncertainty in the model structure, on the optimum solution of acid rain abatement. Seven air pollution simulation models were compared on the basis of their performance in managing acid rain concentration. Regret Analysis was applied to identify the best model. In this case, regret was associated with the variability of the results caused by unknown information about future condition because the correct model was unknown.

Uber et al. (1991) described the Robustness Analysis in an investigation of Type II uncertainty in the evaluation of optimal solutions of a waste water treatment plant design. The Robustness measure was defined as "the ability of the system to maintain a given level of performance even if the actual parameter values are different from the assumed values." Robustness Analysis was used to generate alternative designs that represent the trade-off between total system cost and robustness. Two measures of robustness were included, robustness with respect to BOD concentration and robustness with respect to TSS (total suspended solid) concentration. The results showed that each of these two measures lead to different robust designs, while combining the two measures leads to a robust design with higher cost. Uber et al. concluded that, compared to the least cost design, a small increase in cost may give a large improvement in robustness.

Burn and Lence (1992) compared four optimization approaches to determine the best approach for waste load allocation in the presence of Type II uncertainty in a linked simulation and optimization model for the Willamette River in Oregon. The four optimization objectives were to minimize the maximum violation, minimize the maximum regret, minimize the total violation, and to minimize the total regret. Their specification of regret was the difference in the cost and water quality violation based on uncertain input parameters and the cost and water quality violation if the true input parameter was known with certainty. Five input scenarios were included. Each scenario represented the possible combination of hydrologic, meteorologic, and pollutant loading condition. They found that the distribution of waste load allocation for a given total cost was affected by the optimization approach selected.

In a recent study, Cardwell and Ellis (1993) used Regret Analysis to investigate model uncertainty in evaluating waste load allocation for five point sources in the Schuylkill River in Pennsylvania. In this context, regret was interpreted as the deviation in the results caused by incorrect selection of the simulation model. Three water quality simulation models were analyzed to address Type I uncertainty. They were the Streeter-Phelps equation, QUAL2E, and WASP4 models. Two measures of regret were applied, the regret based on frequency and the regret based on magnitude. They found that different simulation model leads to a different result. Streeter-Phelps model gives the most conservative results while WASP4 give the least conservative results.

Table 2.1 Water Quality Simulation Models

Models	Runoff	Erosion	Chemical	Distributed/ Lumped	Continuous/ Event
ACTMO	x	x	x	D	C
AGNPS	x	x	x	D	E
ANSWERS	x	x		D	E
ARM/HSP	x	x	x	D	C
CREAMS	x	x	x	L	C
EPIC	x	x	x	L	C
GWLF	x	x	x	D	C
HSP	x	x	x	D	C
HSPF	x	x	x	D	C
LANDRUN	x	x	x	D	C/E
PRMS	x	x		D	C
PRORIL	x	x		D	E
SEDEC		x		D/L	C
SEDIMOT	x	x		D	E
SOILEC		x		D/L	C
SWMM	x	x		D	C/E
SWRRB	x	x		L	C
RUNOFF	x	x		D	E
WEPP	x	x		D	C/E

ACTMO	Agricultural Chemical Transport Model (Free et al. , 1975)
AGNPS	Agricultural Nonpoint Source Pollution Model (Young et al., 1987)
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation Model (Beasly et al., 1980; and Beasly and Huggins, 1982)
ARM/HSP	Agricultural Runoff Management Model (Donigian and Crawford, 1975)
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems Model (Knisel, 1980)
EPIC	Erosion-Productivity Impact Calculator Model (Williams et al., 1982)
GWLF	Generalized Watershed Loading Functions (Haith et al., 1987; and 1992)
HSP	Hydrocomp Simulation Program (Hydrocomp, 1976)
HSPF	Hydrologic Simulation Program Fortran (Donigian et al., 1984)
LANDRUN	Land Runoff Model (Novotny et al., 1979)
PRMS	Precipitation-Runoff Modelling System (EPA, 1971)
PRORIL	Erosion model based on Probability Distribution for Riil Flow and Density (Lewis et al., 1994)
SEDEC	Sediment Economic (Braden et al., 1985)
SEDIMOT	Sedimentology by Distribution Model Treatment (Wilson et al., 1984a; and 1984b)
SOILEC	Soil Conservation Economics Model (Eleveld et al. 1983)
SWMM	Storm Water Management Models (Huber et al., 1981)
SWRRB	Simulator for Water Resources in Rural Basin (Williams, 1985)
RUNOFF	(Borah, 1989a; and 1989b)
WEPP	Water Erosion Prediction Project (Foster, 1987)

CHAPTER 3

SEDIMENT ECONOMIC MODEL (SEDEC)

3.1 Introduction

Several researchers (Wu et al., 1989; and Braden et al., 1989a) have used the SEDEC model for the determination of cost-effective management solutions that would meet sediment criteria for different types of storms or for different sediment delivery estimates. Their solutions for these cases, however, are valid only for the input data they selected. While they recognized the uncertainty in the input data, the effect of the uncertainty was not addressed. In the present study the SEDEC model is extended to include approaches for addressing uncertainty in the model.

There are four reasons why the SEDEC model was chosen for this study:

1. It integrates the physical and economic aspects of the issue;
2. It is not as complicated as ANSWERS or CREAMS but it is not a lumped model either. It allows dividing a watershed into units that have a uniform slope and a uniform management practice. The effect of the soil formation in each land management unit can also be taken into consideration. Furthermore, SEDEC is not a grid system model like ANSWERS, thus more alternative solutions can be analyzed. The ability of the model to solve large problems was demonstrated by Bouzaher et al. (1990);
3. The erosion is estimated based on the well-known Universal Soil Loss Equation (USLE) and the model takes into account the interaction between adjacent fields in estimating the sediment delivered to the stream;
4. Other researchers (Miltz et al., 1988; and Wu et al., 1989) have demonstrated the capability of SEDEC to simulate sediment and to determine a cost-effective management practice aimed at meeting sediment criteria.

SEDEC contains both a simulation and an optimization model. It integrates economic and physical factors that relate to the control of agricultural nonpoint pollution. Regarding the physical factors, the model simulates the movement or the delivery of sediment (erosion and deposition) from agricultural land to a water-body. With respect to the economic factors, the model can be used to identify the management practices for each plot of land that will meet the established erosion criteria. It can also be used to identify a set of management practices that meet the sediment criteria for the entire watershed while minimizing cost. In the SEDEC model, a watershed is divided into Land Management Units (LMUs) based on the uniformity of the slope gradient and on adopted management practice. The model also takes into account the soil formation in each LMU. Each management practice is composed of a combination of crop rotation, tillage system, and mechanical erosion control.

The SEDEC model consists of four parts: the soil economics module (SOILEC), the sediment-path generator module (S-PGEN), the optimization module (OPT), and the dynamic programming module for determining cost efficient solutions (DPSOLVE). A general overview of the program is presented in Table 3.1. This table lists data requirements, computations performed, and output for each of the SEDEC modules. A detailed description of SEDEC is presented in this chapter.

Section 3.2 of this chapter presents the organization of the watershed into LMUs and Transects for the purpose of inclusion in the model. Section 3.3 discusses the estimation of erosion and revenue from each LMU for each management practice using the SOILEC module. Section 3.4 presents the estimation of sediment delivered to the water-body from each Transect using the S-PGEN module. Section 3.5 describes the estimation of the total sediment for the entire watershed corresponding to the optimal solution using the OPT module for all management practices considered. Section 3.6 describes the derivation of the optimum solution of management practices for a specified maximum allowable total sediment load using the DPSOLVE module.

3.2 The Organization of Land Management Units (LMUs) and Transects

To calculate total sediment and total revenue, the watershed is divided into LMUs and Transects. Figure 3.1. shows a schematic picture of how LMUs and Transects are related. A Transect is an array of LMUs that have the same flow direction or flow path for sediment from the ridge line of the watershed to the stream. The flow path is perpendicular to the contours.

An LMU is defined as a plot of land in which the slope can be assumed constant and which has the same management practice. Each LMU is unique in terms of location, land cover, soil formation, type of tillage system, and type of mechanical erosion control. For identification purposes, two subscripts are assigned to each LMU. The first subscript represents the Transect number to which the LMU belongs and the second subscript ranks the distance to the stream relative to other LMUs in the Transect. The numbering of the second subscript is from the stream to the ridge line. For example, $LMU_{1\,3}$ indicates that this LMU belongs to Transect number one and it is the third LMU from the stream.

3.3 The Soil Economics (SOILEC) Module

SOILEC simulates sheet and rill erosion rates and farm revenue per acre, for each LMU and for each set of management practices. It also ranks the management practices for all LMUs based on revenue. Each management alternative is composed of a combination of crop rotation, tillage system, and mechanical erosion control. Examples of crop rotation are corn-soybeans (CS) and corn-soybeans-wheat-meadow (CSWM). The crop rotation CS requires a total period of two years, corn in the first year and soybeans in the second year. The crop rotation CSWM requires a total period of four years, corn in the first year, followed by soybeans in the second year, wheat in the third year, and meadow in the last year. The types of tillage system to be considered are conventional tillage, reduced tillage, and no-till. The types of mechanical erosion control to be considered are vertical cultivation, contour cultivation, contour strip cropping, and terracing. A list of management practices is shown in Table 3.2. The module assumes a planning period which can range from one to 50 years. SOILEC simulates erosion and revenue on an annual basis. For a planning period of one year, SOILEC computes the total erosion and the total revenue for that year. When a series of many years is to be analyzed, the effects of crop yield reduction and increase in cost due to soil loss are also considered. The yearly revenue in a time sequence is discounted to the present and converted to an annual average revenue for the entire planning period. The SOILEC module is based on four basic relationships:

1. the Universal Soil Loss Equation (USLE);
2. the relationship between crop yields and soil loss from erosion;
3. the relationship between cost and soil loss; and
4. the analysis of the discounted net returns.

Input into the SOILEC module are: the range or the list of management practices considered, the total number of years considered, and the discount rate. Management practices are ranked based on the annual average revenue. Management practices with the largest annual average revenue are taken as reference points and compose the baseline scenario of management decisions. The difference in revenue between a given practice and the basic reference set is considered to be the cost of that practice in terms of loss of net annual income per acre.

3.3.1 The Universal Soil Loss Equation (USLE)

The USLE (Wischmeier, 1976; and Wischmeier and Smith, 1978) described in 2.1.2.2.1 is a widely used erosion model. In SEDEC, the length and steepness of slope factor *LS* is determined for each LMU, the soil erodibility factor *K* is determined for each soil formation; the cropping and management factor *C* is determined for each combination of crop rotation and tillage system; and the conservation practices factor *P* is determined for each mechanical erosion control practice.

3.3.2 The Relationship between Crop Yields and Soil Loss

Soil losses result in reduced yield. Therefore, the yield for a particular year is a function of the cummulative soil loss up to that year. The reduction of yields due to erosion has been studied by Kasal

(1976); Taylor and Frohberg (1977); Osteen and Seitz (1978); Boggess et al. (1980); and Kramer et al. (1984). The way SOILEC incorporates this effect is based on the work of Bost (1980). For a single crop under a given management practice, the relationship between crop yield and soil loss from erosion is described as:

$$Y_t = f(DP_t) \tag{3.1}$$

where: Y_t = yield for a crop in a given year t [bushels/acre]; and
DP_t = cummulative depth of top soil loss up to and including year t [inches].

At the beginning of the planning period, DP_t is set equal to zero. As soil erodes over time, the total soil loss grows larger and the yield declines. Therefore, DP_t increases over time. The assumption that soil erosion has a negative impact on long-term productivity has been verified experimentally (Bost, 1980).

The erosion determined by the USLE, in tons per acre, is converted to inches of soil lost. The new soil depth relative to the beginning of the operation is then used to calculate the erosion for the following year. Two important parameters in the USLE (K and C) change with time. The K factor is an inherent soil characteristic that varies with depth $K(DP_{t-1})$. The C factor is an empirical crop management parameter that reflects the residue left by the previous year's crop. It varies with the yield of that previous crop $C(Y_{t-1})$. Therefore, the soil depth, the K factor, the bulk density of the soil horizons and the initial crop yield values are essential input in the SOILEC module. The bulk density is used to convert tons of soil loss into inches of soil lost.

Four erosion phases are incorporated in SOILEC: the uneroded phase (more than four inches of soil horizon A remaining); the moderately eroded phase (less than or equal to four inches of soil horizon A remaining); the severely eroded phase (no soil horizon A remaining); and the very severely eroded phase (top soil is eroded to the underlying parent material). Linear interpolation between yield and soil eroded depth is used to estimate productivity for a given soil within each of these four phases.

3.3.3 The Relationship between Cost and Soil Loss

To maintain crop yield when fields have been eroded, fertilizers or other chemicals used for soil improvement must be applied. This will result in an increase in cost for a particular crop. The cost of maintaining crop yield is determined as follows:

$$BC_t = g(DP_t) \tag{3.2}$$

where: BC_t = budgeted total cost relative to the maximum revenue case in year t for a given soil loss [\$/ton]; and
DP_t = cummulative depth of top soil lost up to and including year t [inches].

The relationship between soil loss and cost is incorporated into SOILEC by assuming that the farmer incurs an additional cost to improve the soil, e.g., special application of fertilizers, at the start of each of the latter three erosion phases, i.e., for the moderately eroded, severely eroded, and very severely eroded phases. The timing of the additional costs depends on the soil formation and management practice applied (Bost, 1980).

3.3.4 The Discounted Net Returns

As previously mentioned, SOILEC simulates sediment loss from each LMU and revenue on an annual basis. Each management practice is characterized by a set of operating costs and revenues. SOILEC calculates the discounted annual net returns on a per acre basis. The sum of discounted annual net returns gives the present value of net returns over a planning horizon for a given management practice. For the multicrop case, the present value of net return is determined as follows:

$$PVNR_{vT} = \sum_{t=1}^{T} \frac{\sum_{c=1}^{CC} PR_c\, Y_{vct} - BC_{vt}}{(1+r)^t} \tag{3.3}$$

where: $PVNR_{vT}$ = present value of net return for management practice v over T years [\$/acre];
PR_c = price of the cth crop [\$/bushel];
Y_{cvt} = yield for the cth crop for management practice v in year t [bushels/acre];
BC_{vt} = budgeted cost relative to the maximum revenue case for management practice v in year t [\$/bushels]; and
r = interest rate [%].

The annual value of the net return is given as:

$$AV_{vT} = PVNR_{vT} * r \tag{3.4}$$

where: AV_{vT} = annual value of net return for management practices v over T years [\$/acre].

3.3.5 The SOILEC Module Output

The output of SOILEC is the identification of efficient management practices. The output is presented in tabular form for each LMU, beginning with the first Transect and the first LMU. Table 3.3 shows an example of the SOILEC output.

The planning period is shown in the first row, i.e., a 50-year planning period. The management practices are listed under the item " #System". There are 12 management practices for each LMU which consist of a combination of three crop rotations, CSWDCS, CS, and CSWM, two tillage systems, NT and CT, and two mechanical erosion controls, VT and CN. For each management practice, the value of the *LS*, *C*, and *P* factors in the USLE and the slope of the LMU, *S*, are listed in the table. This information is followed by the erosion and the farm revenue for each management practice. Also, the farm and field number and the total area of each LMU are listed in the last three columns in Table 3.3 since this is important input to S-PGEN. The management practice with the largest average annual revenue is considered to be the dominant management practice or the basic practice. It is taken as a reference point. The dominant management practice is listed at the first row. As shown in Table 3.3, they are CSWDCS NT VT for $LMU_{1\,1}$, CSWM CT VT for $LMU_{1\,2}$, and CSWDCS NT VT for $LMU_{1\,3}$, with a total revenue of \$129.27/acre/annum, \$8.00/acre/annum, and \$154.48/acre/annum, respectively. Other management practices are considered as non-dominant management practice. These management practices are ranked based on the loss of revenue compared to the dominant management practice. They are listed below the dominant management practice. The loss is in fact an opportunity cost and could be designated as such by the controlling agency in assessments of the economics of different management practices. In this study the economic aspects of the management are stated in terms of farm revenue. For this reason the loss of revenue compared to the dominant management practice will be referred to as the Relative Revenue Reduction (RRR) rather than as a cost.

3.4 The Sediment-Path Generator (S-PGEN) Module

In the SOILEC module, the amount of erosion from each LMU is calculated for each management practice. However, only a portion of the eroded soil is carried to the water-body. S-PGEN uses the sediment delivery ratio (SDR_{ij}) to calculate this portion. Subscript i represents the Transect number and subscript j represents the distance of the LMU from the stream. Using the sediment delivery ratios, the S-PGEN calculates the total sediment load transported to the stream for all combinations of management practice for all LMUs in each Transect. The S-PGEN also adds the corresponding total farm revenue for the LMUs in each Transect. The management practice that results in the largest revenue is considered to be the dominant management practice with zero Relative Revenue Reduction (RRR). Other management practices are ranked on the basis of the actual RRR. Next S-PGEN identifies the combination of all dominant management practices for all LMUs in the Transect. To reduce computational time, the non-dominant set of management practices is not included in the S-PGEN results. The final product of S-PGEN is a set of feasible management practices and the associated RRR and sediment load for each Transect.

3.4.1 The Sediment Delivery Ratio (*SDR*)

The sediment delivery ratio is the portion of the total erosion that ends as sediment in the stream. SEDEC calculates the sediment delivery ratio as proposed by Clarke (1983) and Clarke and Waldo (1986). According to Clarke, the estimation of the sediment delivery ratio is based on two principles. First, as one moves downslope from one LMU to the next, the transport capacity is reduced proportionally to the reduction in the cropping and management factor, the conservation practices factor and the slope factor in the USLE. However, an increase in any of these factors in excess of unity does not affect the transport capacity. Secondly, the deposition along the path is inversely proportional to any reduction in transport capacity. Changes in any of the factors mentioned occur at the boundaries between the LMUs. The sediment delivery ratio is therefore computed at each boundary between the LMUs. The sediment delivery ratio is given by Clarke (1983) and Clarke and Waldo (1986) as follows:

$$SDR_{ij} = \frac{C_{ij-1}}{C_{ij}} * \frac{S_{ij-1}}{S_{ij}} * \frac{P_{ij-1}}{P_{ij}} \tag{3.5}$$

where: SDR_{ij} = sediment transport capacity for the *j*th LMU in Transect *i*;
C_{ij-1} = cropping and management factor in the USLE for the *j*th-*1* LMU in Transect *i*;
S_{ij-1} = slope of the *j*th-*1* LMU in Transect *i*; and
P_{ij-1} = conservation practices factor in the USLE for the *j*th-*1* LMU in Transect *i*.

Since the sediment delivered across the boundary between the *j*th and the *j*th-*1* LMU in a given Transect cannot exceed the erosion originating above that boundary, the following constraints are required:

$$\frac{C_{ij-1}}{C_{ij}} = \frac{C_{ij-1}}{C_{ij}} \quad if\ ratio < 1 \tag{3.6}$$

$$= 1 \quad if\ ratio \geq 1 \tag{3.7}$$

$$\frac{S_{ij-1}}{S_{ij}} = \frac{S_{ij-1}}{S_{ij}} \quad if\ ratio < 1 \tag{3.8}$$

$$= 1 \quad if\ ratio \geq 1 \tag{3.9}$$

$$\frac{P_{ij-1}}{P_{ij}} = \frac{P_{ij-1}}{P_{ij}} \quad if\ ratio < 1 \tag{3.10}$$

$$= 1 \quad if\ ratio \geq 1 \tag{3.11}$$

It is assumed that all sediment at the LMU directly adjacent to the stream entirely enters the stream:

$$SDR_{i0} = 1 \tag{3.12}$$

The total erosion from an LMU is computed by multiplying the per acre erosion rates obtained from SOILEC by the area (in acres) of the LMU. The proportion of erosion that reaches the stream from an LMU in a Transect, ZE_{ij}, is computed as a product of the intervening sediment transport capacity ratios for that Transect, given as:

$$ZE_{ij} = AR_{ij} . A_{ij} . SDR_{ij-1} . \cdots . SDR_{i0} \tag{3.13}$$

where: AR_{ij} = number of acres in the *j*th LMU in Transect *i* [acres]; and
A_{ij} = soil erosion per acre on the *j*th LMU in Transect *i* [ton/acre].

The total sediment delivery to the stream from all LMUs in a Transect is computed as follows:

$$TS_i = \sum_{j=1}^{J} ZE_{ij} \tag{3.14}$$

where: TS_i = cummulative sediment yield from the streambank up to the *j*th LMU in Transect *i* [ton].

3.4.2 The S-PGEN Module Output

The output of the S-PGEN module is presented in tabular form for each Transect. Basically, this output serves as an identification of all possible combinations of management practices under consideration for each Transect. Table 3.4 shows an example of the S-PGEN output.

The optional title name and the total number of Transects in the watershed are listed in the first two rows in Table 3.4. This is followed by the information on each Transect: the Transect number (e.g., Transect 1), the total number of LMUs in Transect 1 (e.g., 3 LMUs), the range of total sediment in Transect 1 (e.g., 27.64 tons/annum to 57.30 tons/annum), and the dominant or the non-dominated number of management sequence (path) for Transect 1 (e.g., 8). A "path" here is a sequence of management practices. It consists of a combination of sets of management practices of all LMUs in the Transect. A dominant management sequence is a sequence of management practices such that there are no other management sequences that have a lower RRR for the same total sediment or the same RRR with a lower total sediment. Then a list of management practices, and their corresponding *C* and *P* parameters, erosion, RRR, slope, area, and farm and field number are presented for each LMU. The difference between this table and the table in the SOILEC output is that the options number of the management practice is listed and the RRR value is added which is the difference in RRR compared to the dominant option. Then, at the end of each Transect a table of the total sediment and the corresponding total RRR is presented for each management sequence. For example, Table 3.4 shows that the set of management practices CSWDCS NT VT is the basic set of management practices for $LMU_{1\,1}$, CSWM CT VT is the basic set of management practices for $LMU_{1\,2}$, and CSWDCS NT VT is the basic set of management practices for $LMU_{1\,3}$. All three basic sets of management practices are listed as management sequence option 1. The combination of these three sets of basic management practices in Transect 1 results in a zero RRR relative to the maximum revenue with a total sediment of 57.3 ton/annum. The sediment is calculated by multiplying the total erosion for each LMU times the sediment delivery ratio. The total sediment delivered over a Transect can then be obtained by the sum of the contributions of all LMUs in the Transect. Other management sequences are ranked based on the total RRR relative to the maximum revenue for each Transect.

3.5 The Optimizer (OPT) Module

This part of SEDEC is designed to determine the least total RRR of control of all possible sediment loads entering the stream. Dynamic Programming (DP) is used in this module. The output is the cummulative sediment load for each Transect and the total RRR of the optimum management sequences. The end product is the total sediment for the entire watershed that enters the stream and the corresponding minimum total RRR. Using this information and given a certain sediment limit, the set of management practices for each Transect can be determined that minimizes the total RRR for the entire watershed. The optimization problem can be formulated as follows (Braden et al., 1984; and Bouzaher et al., 1990):

$$Min\ TRRR = \sum_{i=1}^{IT} \sum_{p=1}^{NP} RRR_{pi}\, N_{pi} \tag{3.15}$$

subject to:

$$\sum_{i=1}^{IT} \sum_{p=1}^{NP} TS_{pi} \le SL_{\max} \tag{3.16}$$

$$\sum_{p=1}^{NP} N_{pi} = 1; \qquad i = 1,....,IT \tag{3.17}$$

$$N_{pi} \in [0,1] \qquad i = 1,....,IT; \qquad p = 1,....,NP \tag{3.18}$$

where: $TRRR$ = total Relative Revenue Reduction for the entire watershed [\$];

RRR_{pi} = Relative Revenue Reduction of selecting management sequence p for Transect j [\$];

N_{pi} = binary number for selected management sequence in Transect i, N_{pi} is equal to 1 if the management sequence is selected, N_{pi} is equal to 0 otherwise;

TS_{pi} = total sediment yield using management sequence p in Transect i [ton];

SL_{max} = maximum allowable sediment load in the stream [ton];

NP = number of dominant management sequences in Transect i; and

IT = number of Transects in the watershed.

The stages of the DP model are the Transects (there are I of these). The state variable is the maximum total sediment to be allocated among the remaining Transects. The decision variables are the sets of management practices p_i for each Transect i. Each Transect has a set of dominant management practices for consideration in the optimization routine. In the DP analysis, first the maximum and minimum possible sediment levels for each Transect are computed. Then, the intermediate levels of sediment that correspond to each of the management practices are determined. For each additional Transect, a cummulative sediment and total RRR are calculated (see Bouzaher et. al., 1990 for a further and more detailed description of the DP programming).

3.5.1 The OPT Module Output

The output of the OPT module is presented in tabular form for each Transect. An example of the OPT module output is presented in Table 3.5. The "T" represents the Transect, each "T" row consists of four records: the first record represents the number of solutions in that Transect, the second and the third record represents the row number of the beginning and the end of the solution in that Transect, and the last record represents the Transect number associated with the following alternative solution. As shown in Table 3.5, the first "T" row is associated with Transect number 2. This is because the Transects are first sorted in ascending order based on the number of steps between the maximum and the minimum total sediment in the Transects. The transect with the smallest number of steps between the maximum and minimum total sediment will be listed on the first "T". The "S" represents the Solution, each "S" row consists of four records. The first record represents the cummulative sediment, the second record represents the cummulative RRR, the third record represents the cummulative sediment at the previous Transect, and the last record represents the dominant solution or the management sequence number in that Transect. The output presents the sets of total revenue and total sediment load for all Transects. The optimal solution for the entire watershed is listed at the last Transect. However, given a certain sediment constraint, the result can be traced back to the management choices implied for all of the previous Transects. Using this information and S-PGEN, the management practices for each LMU can be determined.

3.6 The Dynamic Program Solution (DPSOLVE) Module

The output from the OPT module is the complete list of trade-offs between sediment tolerated in the stream and total RRR for the entire watershed for all management practices under consideration. A point on the trade-off curve represents a set of dominant management practices for a given sediment load. This information is the input to the DPSOLVE module.

In DPSOLVE, the user specifies the maximum allowable total sediment entering the stream. Using the optimization result, DPSOLVE presents a summary of the optimal total RRR that corresponds to a given sediment limitation. Table 3.6 shows an example of the DPSOLVE output for a maximum allowable total sediment of 50 tons. The total RRR associated with the total sediment of 48.10 tons/annum is $80.40/annum. This total sediment and total RRR was obtained by applying the combined set of management practices option 3 for Transect 4, option 1 for Transect 3, option 1 for Transect 2, and option 2 for Transect 1.

Figure 3.1 Schematic of LMUs and Transects

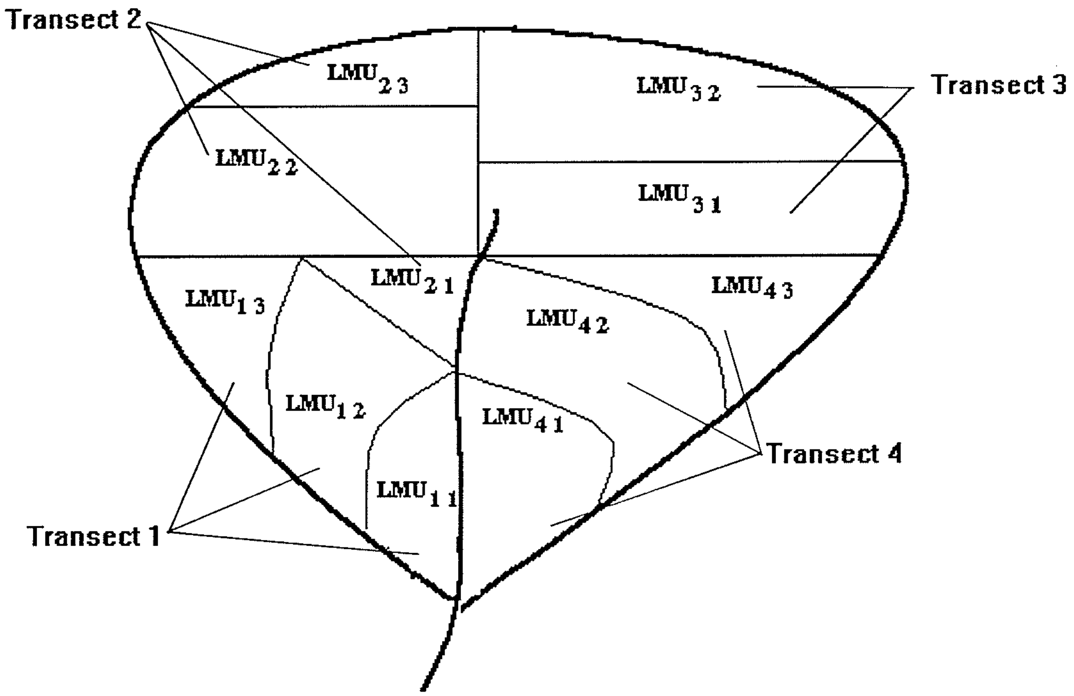


Table 3.1 General Overview of the SEDEC Model

SOILEC Module

Data: Configuration of Transects and LMUs. Soil formation and descriptions; management options with crop budgets; yields; and crop residue estimates. Coefficients for the USLE; discount rates and planning horizon.

Computes: Erosion rates and long term net return for each possible management practice for each LMU. Rank orders the management practices for each LMU in order of the total revenue associated with them.

Output: Management practices for each LMU.

S-PGEN Module

Data: SOILEC output; physical and management interrelationships between LMUs.

Computes: Total sediment deposition and total revenue for all combinations of erosion management practices from SOILEC for all LMUs in each Transect. Rank orders the combinations of management practices that achieve a specified sediment deposition rate for each Transect in order of the revenue.

Output: The sequences of management practices for each Transect that achieve the range of sediment loads of interest and their corresponding total revenue.

OPT Module

Data: S-PGEN output for all Transects; "step" size specifications to control the accuracy and speed of the discrete optimization algorithm.

Computes: Total RRR for the entire study area to comply with each sediment constraint. Rank orders the feasible management sequences for the entire watershed that achieve a given sediment constraint in order of total revenue.

Output: The sequences of management practices for all Transect for all possible total sediment load entering the stream.

DPSOLVE Module

Data: OPT output for the entire study area and a specified sediment constraint.

Computes: The maximum revenue combination of management practice for the entire study area for a particular sediment constraint.

Output: The sediment constraint and the corresponding total revenue.

Compiled based on Braden et al. (1984)

Table 3.2 Alternative Management Practices

Crop Rotation	Tillage Systems	Mechanical Control
Corn-Soybeans (CS)	Fall Plowing (FP)	Vertical Cultivation (VT)
Corn-Soybeans-Wheat-Double-Crop-Soybeans (CSWDCS)	Conventional Tillage (CT)	Contour Cultivation (CN)
Corn-Soybeans-Wheat-Meadow (CSWM)	No-Till (NT)	Strip Cropping (ST)
Corn-Corn-Soybeans-Wheat-Meadow-Meadow-Meadow-Meadow (CCSWMMMM)		Terracing (TR)
Continuous Cover (COVER)		

Table 3.3 Example of the SOILEC Module Output

```
# LONG-RUN    50 Years
------------------------------------------------------------------------------------
# System                LS      C      P     S  Erosion  Income     TR LMU FM FD  AREA
------------------------------------------------------------------------------------
CSWDCS   NT    VT      0.53   0.041  1.00  4.0   1.37   129.27   B   1   1   6  13  21.0
CSWDCS   CT    VT      0.53   0.189  1.00  4.0   6.26    -2.05   D   1   1   6  13  21.0
CSWDCS   NT    CN      0.53   0.041  0.50  4.0   0.68    -3.44       1   1   6  13  21.0
CSWDCS   CT    CN      0.53   0.189  0.50  4.0   3.13    -5.26   D   1   1   6  13  21.0
CS       NT    VT      0.53   0.069  1.00  4.0   2.28   -16.12   D   1   1   6  13  21.0
CS       CT    VT      0.53   0.250  1.00  4.0   8.28   -16.80   D   1   1   6  13  21.0
CS       NT    CN      0.53   0.069  0.50  4.0   1.14   -19.54   D   1   1   6  13  21.0
CS       CT    CN      0.53   0.250  0.50  4.0   4.13   -20.01   D   1   1   6  13  21.0
CSWM     CT    VT      0.53   0.094  1.00  4.0   3.11   -27.81   D   1   1   6  13  21.0
CSWM     NT    VT      0.53   0.061  1.00  4.0   2.02   -29.98   D   1   1   6  13  21.0
CSWM     CT    CN      0.53   0.094  0.50  4.0   1.55   -31.22   D   1   1   6  13  21.0
CSWM     NT    CN      0.53   0.061  0.50  4.0   1.01   -33.42   D   1   1   6  13  21.0

# LONG-RUN    50 Years
------------------------------------------------------------------------------------
# System                LS      C      P     S  Erosion  Income     TR LMU FM FD  AREA
------------------------------------------------------------------------------------
CSWM     CT    VT      0.87   0.107  1.00  6.3   6.81     8.00   B   1   2   7  17  15.8
CSWDCS   NT    VT      0.87   0.081  1.00  6.3   5.32    -0.52       1   2   7  17  15.8
CSWM     NT    VT      0.87   0.113  1.00  6.3   7.41    -2.34   D   1   2   7  17  15.8
CSWM     CT    CN      0.87   0.107  0.50  6.3   3.40    -2.82       1   2   7  17  15.8
CSWDCS   NT    CN      0.87   0.081  0.50  6.3   2.61    -3.31       1   2   7  17  15.8
CS       NT    VT      0.87   0.159  1.00  6.3  10.49    -3.81   D   1   2   7  17  15.8
CSWDCS   CT    VT      0.87   0.220  1.00  6.3  14.00    -4.41   D   1   2   7  17  15.8
CSWM     NT    CN      0.87   0.113  0.50  6.3   3.65    -5.10   D   1   2   7  17  15.8
CS       CT    VT      0.87   0.274  1.00  6.3  17.43    -5.63   D   1   2   7  17  15.8
CSWDCS   CT    CN      0.87   0.220  0.50  6.3   7.00    -6.05   D   1   2   7  17  15.8
CS       NT    CN      0.87   0.159  0.50  6.3   5.14    -6.11   D   1   2   7  17  15.8
CS       CT    CN      0.87   0.274  0.50  6.3   8.72    -7.17   D   1   2   7  17  15.8

# LONG-RUN    50 Years
------------------------------------------------------------------------------------
# System                LS      C      P     S  Erosion  Income     TR LMU FM FD  AREA
------------------------------------------------------------------------------------
CSWDCS   NT    VT      0.18   0.037  1.00  1.0   0.42   154.48   B   1   3   8  16  23.0
CSWDCS   CT    VT      0.18   0.180  1.00  1.0   2.02    -1.69   D   1   3   8  16  23.0
CSWDCS   NT    CN      0.18   0.037  0.60  1.0   0.25    -3.49       1   3   8  16  23.0
CSWDCS   CT    CN      0.18   0.180  0.60  1.0   1.21    -5.15   D   1   3   8  16  23.0
CS       NT    VT      0.18   0.058  1.00  1.0   0.65   -13.74   D   1   3   8  16  23.0
CS       CT    VT      0.18   0.233  1.00  1.0   2.61   -14.10   D   1   3   8  16  23.0
CS       NT    CN      0.18   0.058  0.60  1.0   0.39   -17.23   D   1   3   8  16  23.0
CS       CT    CN      0.18   0.233  0.60  1.0   1.57   -17.55   D   1   3   8  16  23.0
CSWM     CT    VT      0.18   0.090  1.00  1.0   1.00   -40.95   D   1   3   8  16  23.0
CSWM     NT    VT      0.18   0.060  1.00  1.0   0.67   -43.18   D   1   3   8  16  23.0
CSWM     CT    CN      0.18   0.090  0.60  1.0   0.60   -44.43   D   1   3   8  16  23.0
CSWM     NT    CN      0.18   0.060  0.60  1.0   0.40   -46.66   D   1   3   8  16  23.0
------------------------------------------------------------------------------------
```

Table 3.4 Example of the S-PGEN Module Output

```
Title : Example Watershed
The Number of Transects :   4
Transect    1
Number of LMUs  :    3
Sediment Range : High      57.30   Low       27.64
Number of paths passing the FARM AND FIELD CONSTRAINTS :          1728
Number of INITIALLY NON-DOMINATED  paths  :             8
Number of paths :     8

LMU Option     Crop    Till Mech       C         P         Erosion   RRR     S    AREA    FM  FD
--------------------------------------------------------------------------------------------------
1        1    CSWDCS  NT    VT       0.041     1.00         1.37     0.00  4.00  21.00     6   13
         2    CSWDCS  CT    VT       0.189     1.00         6.26     2.05
         3    CSWDCS  NT    CN       0.041     0.50         0.68     3.44
         4    CSWDCS  CT    CN       0.189     0.50         3.13     5.26
         5    CS      NT    VT       0.069     1.00         2.28    16.12
         6    CS      CT    VT       0.250     1.00         8.28    16.80
         7    CS      NT    CN       0.069     0.50         1.14    19.54
         8    CS      CT    CN       0.250     0.50         4.13    20.01
         9    CSWM    CT    VT       0.094     1.00         3.11    27.81
        10    CSWM    NT    VT       0.061     1.00         2.02    29.98
        11    CSWM    CT    CN       0.094     0.50         1.55    31.22
        12    CSWM    NT    CN       0.061     0.50         1.01    33.42
2        1    CSWM    CT    VT       0.107     1.00         6.81     0.00  6.30  15.80     7   17
         2    CSWDCS  NT    VT       0.081     1.00         5.32     0.52
         3    CSWM    NT    VT       0.113     1.00         7.41     2.34
         4    CSWM    CT    CN       0.107     0.50         3.40     2.82
         5    CSWDCS  NT    CN       0.081     0.50         2.61     3.31
         6    CS      NT    VT       0.159     1.00        10.49     3.81
         7    CSWDCS  CT    VT       0.220     1.00        14.00     4.41
         8    CSWM    NT    CN       0.113     0.50         3.65     5.10
         9    CS      CT    VT       0.274     1.00        17.43     5.63
        10    CSWDCS  CT    CN       0.220     0.50         7.00     6.05
        11    CS      NT    CN       0.159     0.50         5.14     6.11
        12    CS      CT    CN       0.274     0.50         8.72     7.17
3        1    CSWDCS  NT    VT       0.037     1.00         0.42     0.00  1.00  23.00     8   16
         2    CSWDCS  CT    VT       0.180     1.00         2.02     1.69
         3    CSWDCS  NT    CN       0.037     0.60         0.25     3.49
         4    CSWDCS  CT    CN       0.180     0.60         1.21     5.15
         5    CS      NT    VT       0.058     1.00         0.65    13.74
         6    CS      CT    VT       0.233     1.00         2.61    14.10
         7    CS      NT    CN       0.058     0.60         0.39    17.23
         8    CS      CT    CN       0.233     0.60         1.57    17.55
         9    CSWM    CT    VT       0.090     1.00         1.00    40.95
        10    CSWM    NT    VT       0.060     1.00         0.67    43.18
        11    CSWM    CT    CN       0.090     0.60         0.60    44.43
        12    CSWM    NT    CN       0.060     0.60         0.40    46.66
--------------------------------------------------------------------------------------------------
     Sediment          RRR        Options
---------------------------------------------
       57.30           0.00       1  1  1
       43.01          44.56       1  4  1
       28.54          72.24       3  1  1
       28.52         116.80       3  4  1
       27.94         141.92       3  7  1
       27.82         161.19       3  9  1
       27.71         222.19       3  7  3
       27.64         241.46       3  9  3
---------------------------------------------
```

Table 3.5 Example of the OPT Module Output

```
     Sediment                     Sediment
     at stage        RRR          at stage   Options
      n                           n-1
-----------------------------------------------------------
T      2              2            3           2
S      7.7            8.2          0.0         2
S      15.6           0.0          0.0         1
T      4              5            8           4
S      11.0           77.9         7.7         3
S      11.0           22.0         7.7         2
S      13.3           8.2          7.7         1
S      21.2           0.0          15.6        1
T      5              10           14          3
S      14.0           60.7         11.0        6
S      14.1           31.3         11.0        3
S      16.4           7.5          13.3        3
S      19.5           8.2          13.3        1
S      27.4           0.0          21.2        1
T      12             16           27          1
S      41.9           192.5        14.1        6
S      42.7           103.6        14.1        3
S      44.9           89.7         16.4        3
S      48.1           80.4         19.5        3
S      55.9           72.2         27.4        3
S      59.4           62.0         16.4        2
S      62.5           52.7         19.5        2
S      70.4           44.6         27.4        2
S      71.4           31.3         14.1        1
S      73.7           17.5         16.4        1
S      76.8           8.2          19.5        1
S      84.7           0.0          27.4        1
-----------------------------------------------------------
```

Table 3.6 Example of the DPSOLVE Module Output

```
 *******  OPTIMAL SOLUTION  *******

      TRRR  =    80.40
      SED   =    48.10

    TRANSECT:    OPTION:
      4            3
      3            1
      2            1
      1            2
```

CHAPTER 4

METHODS OF ANALYZING UNCERTAINTY

Three management policies are considered in this analysis of uncertainty in nonpoint source water quality management, they are the Least Cost policy, the Erosion Tax policy, and the Erosion Standard policy. While the final choice between these policies is influenced by many factors that are beyond the scope of this study, robustness with respect to uncertainty in the input parameters, is an important consideration. With each management policy one can identify the optimum set of agricultural land management practices, but only for a given set of input parameter values. When the input is uncertain or stochastic in nature then optimum management is also uncertain the best set of management alternatives is then the robust set. It is the set that performs best for a range of values that can be expected for the input parameters. A primary goal of the uncertainty analysis is therefore to determine how robust each of these management policies is.

This chapter describes the methods of analyzing uncertainty that were used in this research. Monte Carlo Simulation was used to evaluate the sensitivity of a given management policy to uncertain model input. Modified Generalized Sensitivity Analysis was used to identify the important parameters in the linked process of water quality simulation and optimization for nonpoint source pollution control. Regret and Robustness Analyses were used to determine the set of land management practices that is robust to uncertain model input. The SEDEC model, described in Chapter 3, was used along with these techniques to estimate erosion, sediment load and net income and to obtain the optimum set of land management practices for a given set of input data, allowable sediment load, and management policy.

4.1 Monte Carlo Simulation

In Monte Carlo Simulation each of the uncertain input parameters in a model is treated as a random variable with a distinct probability distribution. The type of probability distribution for each variable is chosen by inspecting the corresponding sampling distributions of the field data.

The parameters of the distributions are estimated from the data. The distributions used in this thesis are two-parameter distributions and can be expressed in the following form:

$$Z = \mu_Z + \sigma_Z F_Z \tag{4.1}$$

where: Z = value of variable Z;
μ_Z = mean value of variable Z;
σ_Z = standard deviation of variable Z; and
F_Z = standardized frequency factor, which is a function of the recurrence interval and the type of distribution.

Estimates of the mean and the standard deviation can readily be obtained from field data. The standard deviation represents the uncertainty of the input parameter. For the case study discussed in Chapter 5, only normal and log normal probability distributions are used. In Monte Carlo Simulation, sets of equally probable values of the input parameters are generated. When the parameters are entered in the model, the model produces a series of outcomes that are also equally probable. This allows the model output to be put in the form of a frequency distribution. Confidence limits can be derived from this distribution. It is necessary to verify whether the distribution functions of the input generated for Monte Carlo Simulation are similar to the respective parent distributions. This similarity can be expected to depend on the number of simulations (Whitehead and Young, 1979).

4.1.1 Determining the Sensitivity of the Three Management Policies

As mentioned in the literature review, the study of Miltz et al. (1988) showed that for the Highland Silver Lake Watershed in Illinois the Erosion Standard policy is more efficient than the Erosion Tax policy when the total sediment load is less than 100 tons. Their study used deterministic data. Different input data, however, could lead to a different conclusion. In other words, the question of which policy is best depends on the specific set of input data used. The question addressed in this thesis is which management policy will meet the goals of water quality control best for the entire range of expected input data, i.e., which management policy is robust to uncertain input data? For this purpose, the study by Miltz et al. is extended in the present study by incorporating the uncertainty in the input parameter and by identifying the least sensitive management policy. Monte Carlo Simulation is used to analyze how sensitive the three management policies are to uncertainty in the input parameters by examining the range of the model output for a large number of randomly generated input parameters. To the knowledge of the author, this issue has not been addressed by other researchers.

4.1.2 The Number of Simulations

The number of simulations that is required varies from one situation to another depending on the complexity of the model, the number of uncertain input parameters, and the variability of the parameters. There is no standard method to determine what number is sufficient. To obtain a perfect match between the theoretical distribution and the simulation output an infinite number of simulations would be required. A practical approach is to generate simulations until the results become stable. Some researchers use experience to judge the stability of the results of a Monte Carlo Simulation (Gardner et al., 1980a; and 1980b; and Fedra, 1983). Others (Hornberger, 1980; and Rubenstein, 1981) use a statistical test to judge the degree of stability. In the present research, the adequacy of the number of simulation was evaluated qualitatively by eyes. In this case, simulations are added until additional realizations cause no important change in the results, i.e., until three decimal.

4.2 Generalized Sensitivity Analysis

4.2.1 Original Development

The Generalized Sensitivity Analysis approach was developed by Spear and Hornberger (1980) to determine which parameters are significant and should be used in a simulation model. The analysis consists of three components: a Monte Carlo Simulation, a classification algorithm and a statistical analysis. Monte Carlo Simulation is used to generate a large number of model outputs corresponding to random values of the input parameters. This technique has been discussed in previous sections. The sections that follow deal with the classification algorithm and the statistical analysis.

4.2.1.1 Classification Algorithm

The classification algorithm separates the Monte Carlo Simulation output into two categories, the Behaviour and the Non-Behaviour category. A model is generally judged by its ability to reproduce observed field conditions. If, therefore, a particular model output is within a reasonable range of the observations, it is included in the Behaviour category. Otherwise, it is put in the Non-Behaviour category. The range is to a degree arbitrary. In this study values within 10% to 30% of the observed values are included in the Behaviour category. Those outside this range are placed in the Non-Behaviour category. Once this is done the corresponding input parameter sets are separated and also placed in the two categories. Parameter values which produced model output that is within a reasonable range of the observation are put in the Behaviour category. Those who did not are put in the Non-Behaviour category. The Behaviour and the Non-Behaviour categories for all input parameters are then assembled in a matrix and subject to a statistical analysis.

4.2.1.2 Statistical Analysis

The values for each parameter in the Behaviour and the Non-Behaviour categories are presented in the form of two empirical cummulative distribution functions. When a parameter has no effect on the outcome of the model it tends to produce values indiscriminately in the Behaviour and the Non-Behaviour categories. If there is a strong effect then one can expect the two distributions to be quite different. The maximum distance between parameter values in the two distributions is therefore a measure of the importance of the parameter. The Kolmogorov-Smirnov test is a non-parametric test that can be used to test the null hypothesis that the difference between two distributions is due to chance. In this context that would mean that the parameter that is tested is not significant. The Kolmogorov-Smirnov (K-S) statistic can be defined as follows:

$$d_{mn}^{x} = \frac{SUP}{X} \left| SA_m (X) - SA_n (X) \right| \tag{4.2}$$

where: $d_{mn}{}^{x}$ = maximum distance between the CDFs;
X = given parameter;
m = number of items in the Behaviours category;
n = number of items in the Non-Behaviours category; and
$SA_m(X)$ and $SA_n(X)$ = sample CDFs for the Behaviour and the Non-Behaviour categories of parameter X.

Figure 4.1 shows an example of the two sample CDFs for the Behaviour and the Non-Behaviour categories where the d_{mn} value is large for an arbitrary parameter X. The parameter is important for the model output. Figure 4.2 shows an example of the sample CDFs for the Behaviour and the Non-Behaviour categories for parameter X where the d_{mn} value is small, and therefore the parameter is not important to the model output.

The advantage of identifying the important input parameters by means of the Generalized Sensitivity Analysis is that it is simple and direct. A disadvantage of the Generalized Sensitivity Analysis is that a subjective decision is needed to define the binary classification.

4.2.2 The Modified Generalized Sensitivity Analysis for Linked Simulation and Optimization Models

Lence and Takyi (1992) modified the Generalized Sensitivity Analysis for a study of point source pollution in which both simulation and optimization are used. When optimization is linked to simulation, one important question is: How sensitive are the optimization model results to uncertainty in the simulation model input parameters? In this case, the classification algorithm cannot be based on observed field conditions. Lence and Takyi (1992) addressed this issue by basing the classification algorithm on a comparison of the linked simulation and optimization model output with a deterministic solution of the simulation and optimization process. The deterministic solution is the optimization result for the case where historic inputs to the simulation model are chosen, or estimated. A reasonable, acceptable range of deviations from the deterministic solution can be chosen for the purpose of defining the classification algorithm. The Kolmogorov-Smirnov statistic test is then used to identify the important input parameters. Lence and Takyi applied the Modified Generalized Sensitivity Analysis in a study of managing dissolved oxygen on the Willamette River.

4.2.3 The Modified Generalized Sensitivity Analysis for Nonpoint Source Water Quality Management

In the present research, the Modified Generalized Sensitivity Analysis of Lence and Takyi (1992) is applied to determine the important model parameters for nonpoint source pollution control. Figure 4.3 shows the components of the Modified Generalized Sensitivity Analysis schematically. The process is as follows.

Randomly generated values of the stochastic input parameters combined with the appropriate values of the fixed input parameters are entered into the simulation and optimization model. The simulation part of the model simulates the erosion deposition process, while the optimization part of the model determines the optimal management solution that meets the water quality criterion for each set of inputs. For each combination of input data this results in an optimal management solution and a corresponding sediment yield for the entire watershed. The next step is to separate the results into Behaviour and Non-Behaviour categories.

The classification algorithm requires a basis for comparison. In this work, the erosion, the total sediment and the revenue are determined for optimum solutions of nonpoint source management using a deterministic set of hydrologic and agricultural production parameters. This comparison basis is used for each of the three management policies, the Least Cost, Erosion Tax, and Erosion Standard policy.

Two types of classification bases are used: a Watershed based classification and a Farm based classification. With the Watershed based classification, each Monte Carlo realization is classified in the Behaviour category if the total sediment and the total revenue for the entire watershed are within a specified range of the total sediment load and the total revenue that would result from the deterministic set of input data. In the Farm based classification, each Monte Carlo realization is classified in the Behaviour category if the erosion and the revenue from each farm field are within a specified range of the erosion and the revenue that would result from the deterministic set of input data.

Typical values for the acceptance range for erosion, total sediment load, and total revenue are 10% to 30% of the values obtained for the deterministic input. Once the model output is classified in the Behaviour and the Non-Behaviour categories, the cummulative distribution functions associated with each parameter in the Behaviour and the Non-Behaviour categories can be developed.

The next step is to perform the Kolmogorov-Smirnov two sample test to investigate the significance of the parameter under investigation. This result in a set of d_{mn} values that measure the separation between Behaviour and Non-Behaviour sets for each parameter and each management policy. Table values of the K-S statistic for the null hypothesis were obtained from Daniel (1978). The d_{mn} values may be expected to be different for the three management policies under consideration. This requires that the separation measurements be standardized so that they are comparable. The standardization is accomplished by dividing each d_{mn} by the estimated d_{mn} value at the significance level of α. The result is called the sensitivity index. It is defined as follows:

$$s^x = \frac{d_{mn}^{\ x}}{d_{mn}^{\ \alpha}} \tag{4.3}$$

where: s^x = sensitivity index for parameter x;
$d_{mn}^{\ x}$ = K-S test for parameter X with n number of the Non-Behaviours and m number of the Behaviours; and
$d_{mn}^{\ \alpha}$ = theoretical d_{mn} at significant level α.

A sensitivity index greater than 1.0 indicates that the parameter is significant at the chosen level of significance, while a sensitivity index less than 1.0 indicates that the parameter is not significant at this level. The theoretical d_{mn} at significant level α were obtained from Daniel (1978).

4.3 Regret and Robustness Analyses

Regret and Robustness Analyses are used to determine the robust set of land management practices for a given region-wide management policy. Regret is used as a measure of the discrepancy of the model output from the true values. Robustness is used as a measure that indicates with what frequency a certain level of management performance is reached. The goal is to obtain a set of agricultural practices which are likely to be satisfactory for unknown future conditions. A complication is that the robust set of management practices for the entire watershed may not be the robust set for individual farms. Two types of analysis were therefore performed, one aimed at identifying the robust management practices from the farm unit point of view and one from the point of view of the entire watershed. In other words, under the Watershed based analysis the goal is to obtain a set of management practices for the entire watershed that are robust in terms of total revenue and total sediment for the entire watershed. Under the Farm based analysis the goal is to obtain management practices for the individual farm fields that are robust in terms of revenue and erosion for each individual farm field.

4.3.1 Regret Analysis

In the sections that follow the Regret Analysis is discussed first for the entire watershed and then for the individual farms. Each of the two Regret Analyses consists of four steps: a definition of regret, Monte Carlo Simulations, the development of a matrix of management decisions for the given Monte Carlo realizations, and the development of a regret matrix for the decision matrix.

4.3.1.1 Regret Analysis Based on the Entire Watershed

For each Monte Carlo realization of input parameters or each input scenario, regret is measured for all possible sets of management decisions and all LMUs. The definition of regret for a Watershed based analysis is the difference between the total revenue or total sediment load under a given set of management decisions and the total revenue or total sediment load resulting under the set of management decisions that have the maximum total revenue.

The regret associated with revenue is called revenue regret and the regret associated with sediment is called sediment regret. Each regret is interpreted as the Relative Revenue Reduction (RRR) or the cost of not applying the optimal set of management decisions for the given input. A set of land use management practices that results in a lower sediment load than the optimal set of decisions is considered to be over-designed; and the converse is considered to be under-designed. The goal is to obtain a set of management practices that has the smallest revenue regret and the smallest sediment regret among all sets of management practices and all input scenarios.

Monte Carlo Simulation is used to generate random parameter values and to apply these in the simulation and optimization model. Each set of input scenarios consists of a set of fixed conditions and a set of stochastic parameters that are estimated in the Monte Carlo Simulation. For each input data set, the optimal solution, i.e., the best set of management practices for the entire watershed can be obtained. An example of Regret analysis is presented in this section using ten Monte Carlo realizations of input parameters generated for illustration purposes. These result in ten optimal solutions for the entire watershed. The Monte Carlo simulation and optimization results are used to illustrate the matrix of the sets of management decisions and the regret matrix.

The matrix of the sets of management decisions for the entire watershed is given in Table 4.1 for revenue values and Table 4.2 for sediment values. The elements in Table 4.1 are the revenues for different sets of management practices under different input scenarios. The first row in Table 4.1 presents the sets of management decisions *MD*. For example, if the watershed consists of seven farm fields, then each set of management decisions *MD* consists of seven sets of management practices, i.e., one set of management practices for each farm field. Each subsequent row of the table represents the ten random input parameter realizations, the input scenarios, *I*. Each column in Columns 2-11 represents the total revenue for a given set of management practices and a given input scenario. This table also shows the maximum revenue which corresponds to the optimal solution for each input scenario in Column 12.

The columns in Columns 2-11 in the matrix correspond to the set of management practices that are identified as optimum for each input scenario. That is, *MD1* is optimal for Input Scenario *1*, and *MD2* is optimal for Input Scenario *2*, and so on. Thus the optimum revenues are found on the diagonal of the matrix. For each input scenario, these values are repeated in Column 12, called RV_{max}. Column 13 of Table 4.1 shows the probability of exceedance associated with each input scenario which is the probability that the selected values of the stochastic parameters are exceeded assuming that they are mutually independent.

A similar matrix of sets of management decisions based on the total sediment in the stream is shown on Table 4.2. The optimal sediment loads corresponding to the optimal set of management practices are found on the diagonal of this matrix.

In mathematical form, the optimal set of management practices in terms of revenue for a given Input Scenario *I* can be expressed as:

$$RV_{\max}{}^{I} = \max_{MD} RV_{MD}{}^{I} \tag{4.4}$$

where: $RV_{max}{}^{I}$ = maximum revenue for Input Scenario *I* [\$/annum]; and
$RV_{MD}{}^{I}$ = revenue using sets of management practices *MD* under Input Scenario *I* [\$/annum].

Table 4.1 shows that the optimal design for Input Scenario *3*, *MD3,* results in the highest revenue among the ten scenarios, namely $43,000.00, while the optimal design for Input Scenario *10*, *MD10,* results in the lowest revenue, namely $31,000.00. The total sediment loads associated with the optimal designs show that *MD10* results in the largest total sediment of 260 tons/annum, while *MD3* results in the smallest total sediment of 150 tons/annum. The probability of exceedance of Input Scenario *3* is the greatest among the input scenarios considered.

There are also two corresponding regret matrices, the revenue regret matrix and sediment regret matrix. They can be developed from the matrix of management decisions and can be calculated as follows:

$$RGr_{MD}{}^{I} = RV_{\max}{}^{I} - RV_{MD}{}^{I} \tag{4.5}$$

$$RGs_{MD}{}^{I} = S_{\max}{}^{I} - S_{MD}{}^{I} \tag{4.6}$$

where: $RGr_{MD}{}^{I}$ = revenue regret using sets of management practices *MD* for Input Scenario *I* [\$/annum];
$RV_{MD}{}^{I}$ = revenue using sets of management practices *MD* for Input Scenario *I* [\$/annum];
$RV_{max}{}^{I}$ = maximum revenue for Input Scenario *I* [\$/annum];
$RGs_{MD}{}^{I}$ = sediment regret using sets of management practices *MD* for Input Scenario *I* [ton/annum];
$S_{MD}{}^{I}$ = sediment using sets of management practices *MD* for Input Scenario *I* [ton/annum]; and
$S_{max}{}^{I}$ = sediment corresponding to $RV_{max}{}^{I}$ [ton/annum].

The revenue regret matrix for 10 Monte Carlo realizations is presented in Table 4.3. The first column shows the input scenario. The first row presents the sets of management decisions *MD* that are optimal sets for each input scenario. The cells in the matrix are the revenue regrets. The last two rows represent the maximum regret and the mean or expected regret for each optimal set of management practices.

The goal of the regret analysis is to identify the robust set of management practices. In terms of revenue regret the robust set can be based on two criteria. One criterion is that the maximum regret is the smallest among all optimal sets of management practices. The other is that the mean or the expected regret over all Monte Carlo realizations is the least. For example: the minimum maximum revenue regret over the 10 Monte Carlo realizations is $6,900.00/annum. This results under the sets of management practices *MD1*, *MD6*, and *MD10*. The row of expected regret shows that *MD6* gives the least expected revenue regret and that *MD10* gives the second lowest expected revenue regret. Therefore, from the point of view of minimizing revenue regret, either *MD6* or *MD10* could be selected. When choosing between these management practices, one must take into account the sediment regret which is discussed next.

The regret matrix for sediment is shown in Table 4.4. The first column represents the input scenario. This column is followed by the sediment regret for a given set of management practices and input scenario. The regret is the difference between the total sediment for a given input scenario using the various optimal sets of management practices (Columns 2 to 11 in Table 4.2) and the total sediment resulting from the optimal design for that input scenario (Column 12 Table 4.2). The regret based on sediment is positive for an over-designed and negative for an under-designed case. The last three rows represent the maximum sediment regret for an over-designed and an under-designed case and the expected sediment regret for each set of management practices. It can be seen that the maximum positive sediment regret (i.e., for an over-designed system) occurs using *MD4*, i.e., a maximum of 160 tons/annum more than the optimal case over all input scenario, and the maximum under-designed system occurs using *MD3*, i.e., a maximum of 425 tons/annum less than the optimal case over all input scenarios. The minimum of the maximum over-designed values for the sediment regret is 0 ton/annum, resulting from *MD3*. The second lowest of the maximum over-designed values for the sediment regret is 50 tons/annum, resulting from *MD2*. The minimum of the maximum under-designed values for the sediment regret is 0 ton/annum, resulting from *MD4*. The second lowest of the maximum under-designed values for the sediment regret is 95 tons/annum, resulting from *MD7*.

In terms of sediment production there are three criteria that can be used to identify the robust set of management practices. One criterion is that the range between the over-designed and under-designed cases is the smallest. The second criterion is that the maximum under-designed value is the least. The third criterion is that the mean or the expected sediment regret is the least among all sets of management practices. For example, the smallest range of the sediment regret for these 10 Monte Carlo realizations is 160 tons/annum, resulting under the set *MD4*. The second lowest range of the sediment regret is 225 tons/annum, resulting under the set *MD7*. The expected sediment regret shows that *MD1* gives the least expected sediment regret and that *MD8* gives the second lowest expected sediment regret. Therefore, from the point of view of minimizing regret with respect to sediment, either *MD1*, *MD4*, *MD7* or *MD8* could be selected.

It can be seen that the robust set of management practices in terms of revenue is not the same as that which is in terms of sediment. A suitable trade-off between the goals of maximizing revenue and meeting the sediment specification must therefore be made. This is a matter of the overall policy of the decision maker. In the example given above, *MD1* can be considered a set of robust management practices in terms of Regret Analysis.

4.3.1.2 Regret Analysis Based on the Farm Unit

For individual farms, the definition of regret for a particular input scenario is the difference between the revenue or erosion at each farm field for the chosen set of management practices and the revenue or erosion at these individual farm fields that would have been obtained for the optimal set of management practices. The optimal set of management practices is determined for each input scenario, i.e., the sets of management practices that gives the highest revenue compared to applying other management practices. The regret in terms of revenue is called revenue regret and the regret in terms of erosion is called the erosion regret. Revenue regret can be interpreted as the cost of not attaining the optimal solution. Management practices that result in an erosion rate less than the erosion based on an optimal management practice is considered to be over-design; and the converse situation is under-design. The goal is to obtain a management practice that has the smallest revenue regret and the smallest erosion regret among all management practices.

When dealing with an individual farm, the matrix of management decisions and the regret matrix must be developed for each individual farm in the watershed. For the watershed used in this example, there would be seven matrices of sets of management decisions for revenue, seven matrices for erosion, seven revenue regret matrices and seven erosion regret matrices. Tables 4.5 to 4.8 show examples of these matrices for revenue and erosion for only one field.

The first row in Tables 4.5 to 4.8 presents the management practices that were identified as the optimum set of land use management practices for this field. Here the management practices are denoted as *M* to distinguish them from the sets of management practices *MD* for the entire watershed. The first column shows the input scenarios. The remaining columns in Table 4.5 show the revenue corresponding to the management practices that were identified as optimum for each input scenario. That is, *M1* is optimal for Input Scenario *1*, and *M2* is optimal for Input Scenario *2*, and so on. Thus, the optimum revenues are found on the diagonal of the matrix. For each input scenario, these values are repeated in the last column, called RV_{max}.

The erosion under each management practice and input scenario corresponding to these cases are shown on Table 4.6. The optimal erosion levels resulting from the optimal sets of management practices are found on the diagonal of this matrix.

Table 4.5 shows that the optimal set of management practices for Input Scenario *10*, *M10,* results in the highest total revenue among the ten scenarios namely \$220.00/acre/annum, while the optimal management practice for Input Scenario *9*, *M9*, results in the lowest total revenue namely

$85.00/acre/annum. The erosion associated with the optimal sets of management practices shows that *M7* results in the highest erosion of 1.90 tons/acre/annum, while *M4* results in the lowest erosion of 0.15 tons/acre/annum.

There are also two regret matrices, the revenue regret matrix and erosion regret matrix. They can be developed similarly to Tables 4.3 and 4.4, respectively. The revenue regret matrix for 10 Monte Carlo realizations is presented in Table 4.7. The cells in the matrix are the revenue regret. The last two rows represent the maximum regret and the mean or expected regret for each management practice.

The goal of the regret analysis is to identify the robust set of management practice. In terms of revenue regret the robust set can be based on two criteria. One criterion is that the maximum regret is the smallest among all sets of management practices and all input scenarios. The other is that the mean or the expected regret over all Monte Carlo realizations is the least. For example: the minimum revenue regret for the 10 Monte Carlo realizations is $55.00/acre/annum. It results from the set of management practices *M7*. The second lowest of the maximum revenue regret values is $60.00/acre/annum. It results from the set of management practices *M1*. The row of expected regret shows that *M7* gives the least expected revenue regret and that *M9* gives the second lowest expected revenue regret. Therefore, from the point of view of minimizing revenue regret, *M7* could be selected. When choosing between these one must take into account the erosion regret which will be discussed next.

The regret matrix for erosion is shown in Table 4.8. The cells in the matrix represent the erosion regret for a given set of management practices and input scenario. The regret is the difference between the erosion for a given input scenario using the various management practices (columns 2 to 11 in Table 4.6) and the erosion incurred under the optimal set of management practices for a given scenario (column 12 Table 4.6). The regret based on erosion is positive for an over-designed and negative for an under-designed case. The last three rows represent the maximum regret for an over-designed and an under-designed case and the expected regret for each set of management practices *M*. It can be seen in Table 4.8 that the maximum over-design occurs using *M4*, i.e., 1.15 tons/acre/annum more than the optimal solution, and the maximum under-design occurs using *M2*, i.e., 3.15 tons/acre/annum more than the optimal solution. The minimum of the maximum over-design value for the erosion regret is 0.00 tons/acre/annum, resulting from the set of management practices *M2*. The second lowest of the maximum over-designed cases for the erosion regret is 0.05 tons/acre/annum, resulting from *M3*. The minimum of the maximum under-designed cases for the erosion regret is 0.00 tons/acre/annum, resulting from *M4*. The second lowest of the maximum under-designed values for the erosion regret is 0.05 tons/acre/annum, resulting from *M5*.

In terms of erosion produced there are three values that can be used to identify the robust management practice. One value is the smallest range between the over-design and under-design regret values. The second is the smallest of the maximum under-design values. The third is the minimum mean or expected erosion regret. For example, the smallest range of the erosion regret for these 10 Monte Carlo realizations is 1.15 tons/acre/annum, resulting from *M4* and *M5*. The second lowest range of the erosion regret is 1.20 tons/acre/annum, resulting from *M10* and *M9*. The expected erosion regret shows that the sets of management practices *M9* gives the least expected erosion regret and that *M6* gives the second lowest expected erosion regret. Therefore, from the point of view of minimizing regret with respect to erosion, management practice *M9* could be selected.

It can be seen that the robust management practice in terms of revenue is not the same as that in terms of erosion. A suitable trade-off between the goals of maximizing revenue and meeting the erosion specification must therefore be made. This is a matter of the overall policy of the decision maker. In the example given above, three potential management practices can be considered robust in terms of Regret Analysis, namely *M7*, *M8*, and *M9*. A further analysis of robustness in quantitative terms is discussed next. The above procedure to obtain robust sets of management practices needs to be carried out for all fields in the system.

4.3.2 Robustness Analysis Based on Probability

The robustness of a given set of management practices was discussed in the previous section in terms of revenue and sediment regret for a range of uncertain input parameters. Minimizing regret is a way of ensuring that the effect of future unfavourable conditions is minimized. The robustness analysis can be improved when the frequency of meeting given sediment or revenue limits is taken into consideration. This leads to the development of a robustness matrix as will be explained below. The matrix can be obtained for the entire watershed or based on individual farm units.

4.3.2.1 Robustness Analysis Based on the Entire Watershed

Robustness is defined as the frequency that given revenue or sediment limits are met for each set of management practices under consideration, given that the input parameters are random variables. There are two robustness measures, one associated with revenue and one associated with sediment.

To develop a robustness matrix, specific revenue and sediment limits must be established. The revenue limits to be allowed can be taken as a certain percentage of the maximum revenue, $RVmax$, from Table 4.1. If γ represents the percentage of the maximum revenue, $RVmax$, one wants to attain, the revenue limit becomes $\gamma RVmax$. The sediment limit can be in terms of total sediment or can be taken as a certain percentage δ of the maximum sediment, $Smax$, from Table 4.2. In the latter case it becomes $\delta Smax$. A set of different levels of γ and δ can be assumed in the investigation.

Once the revenue and sediment limits have been established, Monte Carlo simulations are performed in which the revenue and sediment for given sets of management practices are calculated for different realizations of the random input parameters. The revenue and sediment values produced are then compared with the specified limits and for each set of management practices *MD,* and the frequency that $\gamma RVmax$ and $\delta Smax$ are met is determined. The robustness matrix for revenue based on 10 Monte Carlo realizations is presented in Table 4.9. The first column shows the revenue limits considered; in this case $95\%RVmax$, $90\%RVmax$, and $85\%RVmax$. The first row presents the sets of management practices *MD*. The cells in the matrix show the frequency of meeting the revenue limits under each of these sets of management practices. For illustration purposes only ten input scenarios were generated.

The set of management practices that has the highest frequency of meeting the revenue limits is considered to be the robust set of management practices with respect to revenue. The results show that the set of management practices *MD6* results in the highest frequency for all three revenue limits considered, the 95%, 90%, and 85% of the maximum revenue limits, with frequencies of 40%, 80% and 90%, respectively.

A robustness matrix was also developed for sediment. Table 4.10 presents the robustness matrix for sediment based on these 10 Monte Carlo realizations. The first column shows the sediment limits considered. Here three sediment limits are considered, a maximum total sediment of 100 tons/annum, 150 tons/annum, and 200 tons/annum. The first row presents the sets of management practices, *MD*. The cells in the matrix are the frequency of the input scenarios that met the sediment limits under each set of management practices *MD*. The results show that the set of management practices *MD4* results in the highest frequency for all three sediment limits considered, with total frequencies of 30%, 60% and 90%, respectively. There are two potential sets of management practices that can be considered as robust in terms of Robustness Analysis, set of management practices *MD4* and *MD7*. Set of management practices *MD6* results in a high frequency in terms of robustness with respect to revenue, however *MD6* gives a low frequency in terms of robustness with respect to sediment, therefore it may not be included as a potential robust set of management practices.

4.3.2.2 Robustness Analysis Based on the Farm Unit

Using the individual farm as the basic unit for robustness comparisons, the definition of robustness is the frequency that given revenue and erosion limits are met for various input scenarios for each set of management practices and for each farm field. This again requires two robustness measures, robustness associated with revenue and robustness associated with erosion. The goal is to obtain a management practice that meets the specified revenue and erosion limits most frequently.

In order to develop the robustness matrix, the revenue and the erosion limits considered must first be established. The revenue limits can be taken similar to those for the entire watershed case, i.e., a certain percentage γ from the maximum revenue, *RVmax* in Table 4.5. The erosion limits can be in terms of a given total erosion or they can be in terms of a certain percentage δ from the maximum erosion, *Emax*, from Table 4.6. Thus, the limit of the maximum erosion becomes $\delta Emax$.

When dealing with individual farms a robustness matrix must be developed for each farm field in the watershed. For the watershed in this example, there will be seven robustness matrices for revenue and seven robustness matrices for erosion. Tables 4.11 and 4.12 show examples of the robustness matrix for revenue and erosion for only one farm field. The first row of Table 4.11 presents the management practices *M*, while the first column shows the revenue limits considered. Three revenue limits are included, a 95%, 90%, and 85% of the maximum revenue given in Table 4.5. The cells represent the frequency of fulfilling these revenue limits for each management practice for the ten input scenario. The results show that the sets of management practices *M7* and *M9* have the highest frequency of staying within the three revenue limits with total frequencies of 40%, 60%, and 80%, and 60%, 60%, and 70%, respectively.

Table 4.12 shows the robustness matrix for erosion. The first column shows the erosion limits that were considered, a maximum erosion of 1 ton/acre/annum, 1.5 tons/acre/annum, and 2 tons/acre/annum. The cells represent the frequency of meeting the erosion limits under each set of management practices. The results show that the sets of management practices *M4*, *M5*, and *M10* have the highest frequency of meeting the three erosion limits with a total frequency of 80%, 100%, and 100%, respectively. There are two potential sets of management practices that are considered robust as a result of this Robustness Analysis, *M7* and *M9*.

The results based on the Robustness Analysis are then combined with the results based on the Regret Analysis. A trade-off exist between robustness in terms of regret and robustness in terms of frequency of attaining specified goals. Decision making given such a trade-off depends on the policy adopted by the decision maker.

Figure 4.1 Cummulative Distribution Functions for the Behaviour and the Non-Behaviour Categories for a Significant Parameter X

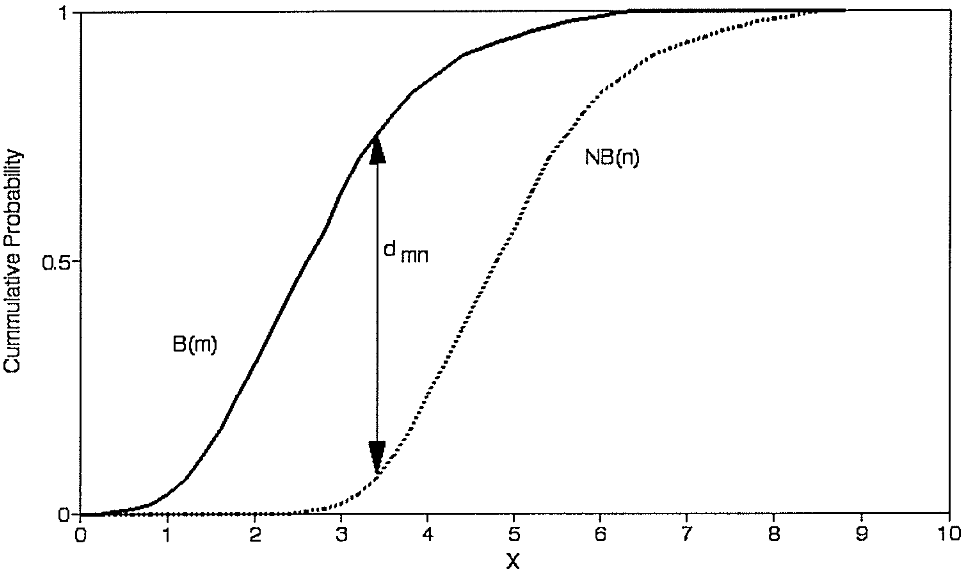
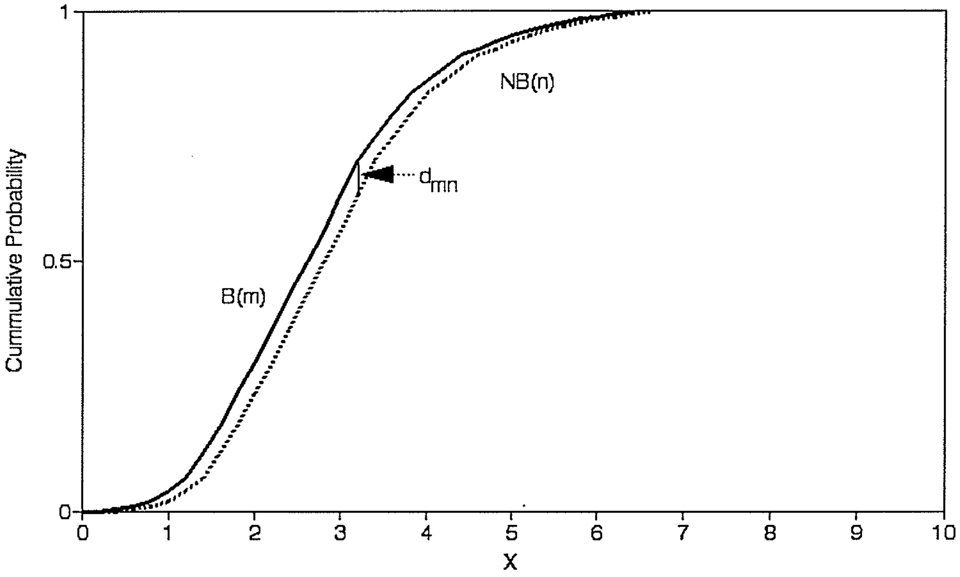


Figure 4.2 Cummulative Distribution Functions for the Behaviour and the Non-Behaviour Categories for a Non-Significant Parameter X



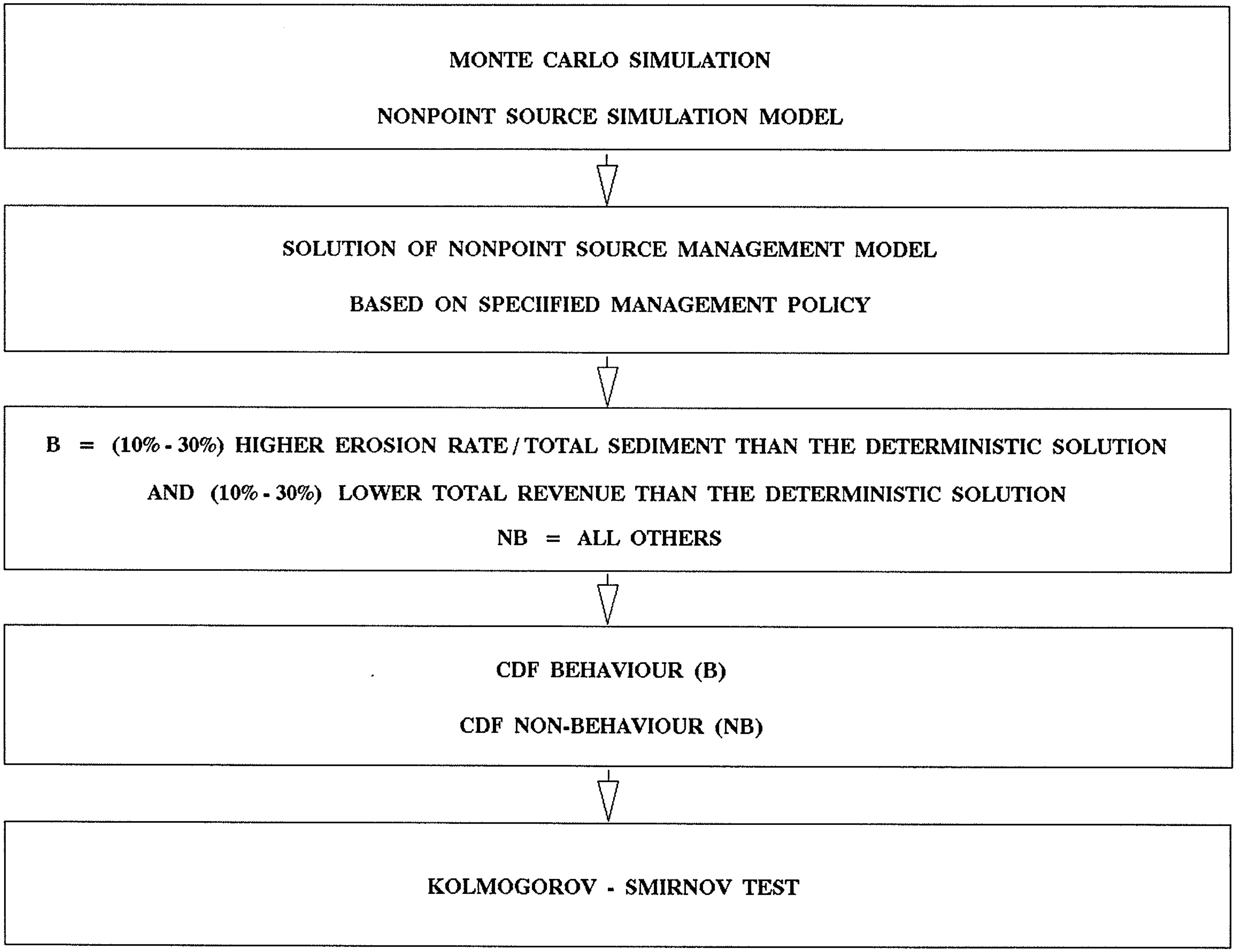


Figure 4.3 Modified Generalized Sensitivity Analysis

Table 4.1 Matrix of Management Decisions and Corresponding Total Revenue under the Watershed Based Analysis for 10 Monte Carlo Realizations

Input Scenario *(I)*	Revenue Using Sets of Management Decisions *(MD)*										*RVmax*	Prob. of Exceedance
	1 $/annum	2 $/annum	3 $/annum	4 $/annum	5 $/annum	6 $/annum	7 $/annum	8 $/annum	9 $/annum	10 $/annum	$/annum	
1	33700	32100	30700	30300	29000	33100	29600	30900	32300	32000	33700	0.09
2	36500	37500	33600	32700	32500	36400	31500	35700	34500	34800	37500	0.14
3	39000	38900	43000	39000	36500	38900	38700	38500	35500	39100	43000	0.18
4	30300	28000	34200	34600	24100	30400	33200	28300	28600	29200	34600	0.05
5	29000	30600	27000	27800	35800	28900	27800	29000	28300	28900	35800	0.11
6	38800	34200	37100	36500	28400	41400	37500	32100	37900	38200	41400	0.14
7	32300	27200	33800	35000	27000	34800	38100	27200	33300	32500	38100	0.04
8	31500	33000	30700	32000	29000	34700	29900	35200	29500	32100	35200	0.08
9	31000	26100	30000	30300	25300	32500	32800	27600	35300	32200	35300	0.09
10	24100	25000	22500	22000	29800	29300	25100	26400	27000	31000	31000	0.08

Table 4.2 Matrix of Management Decisions and Corresponding Total Sediment under the Watershed Based Analysis for 10 Monte Carlo Realizations

Input Scenario *(I)*	Sediment Load Using Sets of Management Decisions *(MD)*										*Smax*	Prob. of Exceedance
	1 tons/ annum	2 tons/ annum	3 tons/ annum	4 tons/ annum	5 tons/ annum	6 tons/ annum	7 tons/ annum	8 tons/ annum	9 tons/ annum	10 tons/ annum	tons/ annum	
1	250	405	610	140	210	280	190	260	200	300	250	0.09
2	155	250	380	90	130	175	120	165	125	185	250	0.14
3	65	100	150	35	55	75	50	65	50	75	150	0.18
4	380	450	440	205	335	455	300	405	310	475	205	0.05
5	205	350	500	120	165	245	160	245	165	255	165	0.11
6	160	275	375	85	135	185	120	265	130	185	185	0.14
7	360	420	520	200	315	400	245	425	285	445	245	0.04
8	290	430	655	155	235	300	200	250	235	345	250	0.08
9	245	460	605	150	215	305	215	295	180	300	180	0.09
10	280	465	645	165	230	330	230	285	215	260	260	0.08

Table 4.3 Regret Matrix for Revenue under the Watershed Based Analysis for 10 Monte Carlo Realizations

Input Scenario *(I)*	Regret Revenue Using Sets of Management Decisions *(MD)*									
	1 $/annum	*2* $/annum	*3* $/annum	*4* $/annum	*5* $/annum	*6* $/annum	*7* $/annum	*8* $/annum	*9* $/annum	*10* $/annum
1	0	1600	3000	3400	4700	600	4100	2800	1400	1700
2	1000	0	3900	4800	5000	1100	6000	1800	3000	2700
3	4000	4100	0	4000	6500	4100	4300	4500	7500	3900
4	4300	6600	400	0	10500	4200	1400	6300	6000	5400
5	6800	5200	8800	8000	0	6900	8000	6800	7500	6900
6	2600	7200	4300	4900	13000	0	3900	9300	3500	3200
7	5800	10900	4300	3100	11100	3300	0	10900	4800	5600
8	3700	2200	4500	3200	6200	500	5300	0	5700	3100
9	4300	9200	5300	5000	10000	2800	2500	7700	0	3100
10	6900	6000	8500	9000	1200	1700	5900	4600	4000	0
Maximum Regret	6900	10900	8800	9000	13000	6900	8000	10900	7500	6900
Expected Regret	3684	4703	4105	4815	6477	2493	4591	5150	4495	3453

Table 4.4 Regret Matrix for Sediment under the Watershed Based Classification for 10 Monte Carlo Realizations

Input Scenario (I)	Regret Sediment Using Sets of Management Decisions (MD)									
	1 tons/annum	2 tons/annum	*3* tons/annum	*4* tons/annum	*5* tons/annum	*6* tons/annum	*7* tons/annum	*8* tons/annum	*9* tons/annum	*10* tons/annum
1	0	-155	-360	110	40	-30	60	-10	50	-50
2	95	0	-130	160	120	75	130	85	125	65
3	85	50	0	115	95	75	100	85	100	75
4	-175	-245	-235	0	-130	-250	-95	-200	-105	-270
5	-40	-185	-335	45	0	-80	5	-80	0	-90
6	25	-90	-190	100	50	0	65	-80	55	0
7	-115	-175	-275	45	-70	-155	0	-180	-40	-200
8	-40	-180	-405	95	15	-50	50	0	15	-95
9	-65	-280	-425	30	-35	-125	-35	-115	0	-120
10	-20	-205	-385	95	30	-70	30	-25	45	0
Maximum Regret (+)	95	50	0	160	120	75	130	85	125	75
Maximum Regret (-)	-175	-280	-425	0	-130	-250	-95	-200	-105	-270
Expected Regret	3	-113	-237	91	35	-27	49	-23	45	-32

Table 4.5 Matrix of Management Decisions and Corresponding Total Revenue under the Farm Based Analysis for 10 Monte Carlo Realizations

Input Scenario *(I)*	Revenue Using Set of Management Decisions *(M)*										*RVmax*	Prob. of Exceedance
	1 $/acre/ annum	*2* $/acre/ annum	*3* $/acre/ annum	*4* $/acre/ annum	*5* $/acre/ annum	*6* $/acre/ annum	*7* $/acre/ annum	*8* $/acre/ annum	*9* $/acre/ annum	*10* $/acre/ annum	$/acre/ annum	
1	170	160	160	125	125	155	165	165	165	125	170	0.09
2	180	190	190	125	125	185	180	175	185	125	190	0.14
3	100	105	105	80	80	100	95	100	100	80	105	0.18
4	170	165	165	185	185	165	160	160	160	185	185	0.05
5	105	65	65	165	165	65	110	95	100	165	165	0.11
6	130	170	170	120	120	175	130	125	130	120	175	0.14
7	160	110	110	140	140	115	160	150	160	140	160	0.04
8	135	95	95	120	120	100	140	140	140	120	140	0.08
9	75	50	50	40	40	55	85	85	85	40	85	0.09
10	165	125	125	210	210	135	190	180	180	220	220	0.08

Table 4.6 Matrix of Management Decisions and Corresponding Erosion under the Farm Based Analysis for 10 Monte Carlo Realizations

Input Scenario *(I)*	Erosion Rate Using Set of Management Decisions *(M)*										*ERmax*	Prob. of Exceedance
	1 tons/acre/ annum	*2* tons/acre/ annum	*3* tons/acre/ annum	*4* tons/acre/ annum	*5* tons/acre/ annum	*6* tons/acre/ annum	*7* tons/acre/ annum	*8* tons/acre/ annum	*9* tons/acre/ annum	*10* tons/acre/ annum	tons/acre/ annum	
1	1.75	2.25	2.25	0.60	0.65	1.35	1.05	1.05	1.25	0.65	1.75	0.09
2	1.15	1.40	1.35	0.40	0.40	0.85	0.65	0.65	0.85	0.40	1.40	0.14
3	1.10	1.35	1.35	0.40	0.45	0.80	0.65	0.65	0.75	0.40	1.35	0.18
4	0.45	0.60	0.60	0.15	0.20	0.35	0.25	0.25	0.25	0.25	0.15	0.05
5	2.85	4.25	4.20	1.10	1.10	2.55	1.70	1.70	1.55	1.10	1.10	0.11
6	1.60	1.80	1.80	0.55	0.55	1.05	0.95	0.95	0.95	0.55	1.05	0.14
7	3.20	4.45	4.45	1.20	1.20	2.70	1.90	1.90	1.90	1.20	1.90	0.04
8	1.20	1.60	1.60	0.40	0.40	0.95	0.70	0.70	0.70	0.40	0.70	0.08
9	1.70	2.30	2.30	0.60	0.60	1.40	1.00	1.00	1.00	0.60	1.00	0.09
10	2.45	3.55	3.55	0.90	0.90	2.15	1.45	1.50	1.50	0.90	0.90	0.08

Table 4.7 Regret Matrix for Revenue under the Farm Based Analysis for 10 Monte Carlo Realizations

Input Scenario *(I)*	Regret Revenue Using Set of Management Decisions *(M)*									
	1 $/acre/ annum	*2* $/acre/ annum	*3* $/acre/ annum	*4* $/acre/ annum	*5* $/acre/ annum	*6* $/acre/ annum	*7* $/acre/ annum	*8* $/acre/ annum	*9* $/acre/ annum	*10* $/acre/ annum
1	0	10	10	45	45	15	5	5	5	45
2	10	0	0	65	65	5	10	15	5	65
3	5	0	0	25	25	5	10	5	5	25
4	15	20	20	0	0	20	25	25	25	0
5	60	100	100	0	0	100	55	70	65	0
6	45	5	5	55	55	0	45	50	45	55
7	0	50	50	20	20	45	0	10	0	20
8	5	45	45	20	20	40	0	0	0	20
9	10	35	35	45	45	30	0	0	0	45
10	55	95	95	10	10	85	30	40	40	0
Maximum Regret	60	100	100	65	65	100	55	70	65	65
Expected Regret	21.60	29.90	29.90	32.05	32.05	29.35	19.58	22.90	19.90	31.25

Table 4.8 Regret Matrix for Erosion under the Farm Based Analysis for 10 Monte Carlo Realizations

Input Scenario *(I)*	Regret Erosion Using Set of Management Decisions *(M)*									
	1 tons/acre/ annum	*2* tons/acre/ annum	*3* tons/acre/ annum	*4* tons/acre/ annum	*5* tons/acre/ annum	*6* tons/acre/ annum	*7* tons/acre/ annum	*8* tons/acre/ annum	*9* tons/acre/ annum	*10* tons/acre/ annum
1	0.00	-0.50	-0.50	1.15	1.10	0.40	0.70	0.70	0.50	1.10
2	0.25	0.00	0.05	1.00	1.00	0.55	0.75	0.75	0.55	1.00
3	0.25	0.00	0.00	0.95	0.90	0.55	0.70	0.70	0.60	0.95
4	-0.30	-0.45	-0.45	0.00	-0.05	-0.20	-0.10	-0.10	-0.10	-0.10
5	-1.75	-3.15	-3.10	0.00	0.00	-1.45	-0.60	-0.60	-0.45	0.00
6	-0.55	-0.75	-0.75	0.50	0.50	0.00	0.10	0.10	0.10	0.50
7	-1.30	-2.55	-2.55	0.70	0.70	-0.80	0.00	0.00	0.00	0.70
8	-0.50	-0.90	-0.90	0.30	0.30	-0.25	0.00	0.00	0.00	0.30
9	-0.70	-1.30	-1.30	0.40	0.40	-0.40	0.00	0.00	0.00	0.40
10	-1.55	-2.65	-2.65	0.00	0.00	-1.25	-0.55	-0.60	-0.60	0.00
Maximum Regret(+)	0.25	0.00	0.05	1.15	1.10	0.55	0.75	0.75	0.60	1.10
Maximum Regret (-)	-1.75	-3.15	-3.10	0.00	-0.05	-1.45	-0.60	-0.60	-0.60	-0.10
Expected Regret	-0.48	-1.02	-1.01	0.56	0.55	-0.15	0.19	0.18	0.14	0.55

Table 4.9 Robust Matrix for Revenue under the Watershed Based Analysis for 10 Monte Carlo Realizations

Criteria $/annum	Robust Revenue Using Sets of Management Decisions *(MD)*									
	1	2	3	4	5	6	7	8	9	10
R1>0.95 RVmax	0.20	0.20	0.20	0.10	0.20	0.40	0.20	0.20	0.20	0.10
R2>0.90 RVmax	0.40	0.40	0.30	0.40	0.20	0.80	0.50	0.30	0.40	0.70
R3>0.85 RVmax	0.70	0.50	0.70	0.80	0.40	0.90	0.60	0.50	0.60	0.80

Table 4.10 Robust Matrix for Sediment under the Watershed Based Analysis for 10 Monte Carlo Realizations

Criteria tons/annum	Robust Sediment Using Sets of Management Decisions *(MD)*									
	1	2	3	4	5	6	7	8	9	10
SL1<100	0.10	0.10	0.00	0.30	0.10	0.10	0.10	0.10	0.10	0.10
SL2<150	0.10	0.10	0.10	0.60	0.30	0.10	0.30	0.10	0.30	0.10
SL3<200	0.30	0.10	0.10	0.90	0.40	0.30	0.60	0.20	0.60	0.30

Table 4.11 Robust Matrix for Revenue under the Farm Based Analysis for 10 Monte Carlo Realizations

Criteria $/acre/annum	Robust Revenue Using Set of Management Decisions *(M)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
R1>0.95 RVmax	0.40	0.30	0.30	0.30	0.30	0.30	0.40	0.40	0.60	0.30
R2>0.90 RVmax	0.60	0.40	0.40	0.30	0.30	0.40	0.60	0.60	0.60	0.30
R3>0.85 RVmax	0.70	0.50	0.50	0.50	0.50	0.50	0.80	0.70	0.70	0.50

Table 4.12 Robust Matrix for Erosion under the Farm Based Analysis for 10 Monte Carlo Realizations

Criteria tons/acre/annum	Robust Erosion Using Set of Management Decisions *(M)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
EL1<1.0	0.10	0.10	0.10	0.80	0.80	0.40	0.50	0.50	0.50	0.80
EL2<1.5	0.40	0.30	0.30	1.00	1.00	0.70	0.80	0.70	0.70	1.00
EL3<2.0	0.70	0.50	0.50	1.00	1.00	0.70	1.00	1.00	1.00	1.00

CHAPTER 5

CASE STUDY - DESCRIPTION

This chapter describes the application of uncertainty analysis to the Highland Silver Lake Watershed in Illinois. The first section describes the watershed, the available data, and the basic assumptions that were made about the agricultural practices and the circumstances that cause nonpoint source pollution in the basin. The second section describes the application of the method of the analysis. The results of the analysis are presented and discussed in Chapter 6.

5.1 Description of the Study Area

5.1.1 Selection

The Highland Silver Lake Watershed in Madison County, Illinois was used as a case study to demonstrate the methods of analyzing uncertainty in nonpoint source water quality management developed in this study. The study area was selected because it has a variety of soil formations and because of the availability of adequate data for the purpose of this study. The area is 289 acres, and although this is small, the physical characteristics of the watershed vary widely and are typical of conditions for much larger watersheds. The Highland Silver Lake Watershed is used mainly for agriculture, and farming practices have caused sediment deposition, nutrient depletion, and pesticide accumulation. The main concern is the sediment which is transported into the Highland Silver Lake. This lake is used for water supply, flood control, and recreation.

The Highland Silver Lake Watershed is divided into 16 Transects and 37 LMUs for the purpose of applying the SEDEC model. These Transects and the LMUs and their descriptions are listed in Table 5.1. The number of LMUs varies among Transects. Transect 5 is an example of a Transect with three LMUs, while Transect 1 is an example of a Transect with two LMUs. Transects 7 and 10 consist of one LMU only. The slopes range from 1% to 23%. The main crop is soybeans, but corn, wheat, and forage crops are also important crops in this watershed (Davenport, 1984).

5.1.2 Data and Assumptions used in Modelling

5.1.2.1 Agricultural Management

The agricultural management practices for this river basin were assumed to be combinations of five crop rotations, three tillage systems, and two mechanical runoff controls. Overall, thirty different combinations of management practices were analyzed for each of the 37 LMUs. A list of management practices used in the study is shown in Table 5.2. They are described below.

5.1.2.1.1 Crop Rotation. The five crop rotations are corn-soybeans (CS), corn-soybeans-wheat-double-crop-soybeans(CSWDCS),corn-soybeans-wheat-meadow(CSWM),corn-corn-soybeans-wheat-meadow-meadow-meadow-meadow (CCSWMMMM), and continuous cover (COVER) such as alfalfa or grass. These are typical crop rotations used by farmers in the Highland Silver Lake Watershed (White et al., 1985). All rotations have specific crop durations of one year except CSWDCS for which two crops are grown in the third year. The crop rotation CS requires a total period of two years, corn in the first year and soybeans in the second year. The crop rotation CSWM requires a total period of 4 years, corn in the first year, followed by soybeans in the second year, wheat in the third year, and meadow in the last year. The crop rotation CCSWMMMM requires a total period of 8 years, corn in the first two years, followed by soybeans in the third year, wheat in the fourth year, and meadow in the last four years. The crop rotation CSWDCS requires a total period of three years, corn in the first year, followed by soybeans in the second year, and wheat and soybeans in the third year. In the third year, soybeans are planted after wheat is harvested (double-crop-soybeans). Continuous cover (COVER) assumes that grass or alfalfa is grown continuously.

5.1.2.1.2 Tillage Systems. Three tillage systems are commonly used in the study area, fall plowing (FP), conventional tillage (CT), and no-till (NT).

With the FP alternative, mold-board plowing is usually performed in the fall. This results in a rough soil surface and preserves some of the previous crop residue. The residue and the soil roughness reduce raindrop impact and runoff, resulting in less erosion. Soil roughness and residue also protect the soil from wind erosion. However, the crop residue left on the soil surface may harbor insects and disease-causing organisms.

The CT alternative involves four tillage operations between fall harvest and spring planting. Immediately after the harvest the field is mold-board plowed which leaves some cover of crop residue. Two shallow tillage operations are performed in the following spring using a disker or a field cultivator. Another shallow tillage with a row cultivator occurs in June.

With the NT alternative, the residue of the previous crop is left in the field during winter and not plowed under. The crop is planted without tillage and a herbicide is used to control weed growth. This alternative is considered to be the most effective way of reducing soil erosion.

Retaining crop residue on the field is one of the most powerful tools available for controlling or reducing soil losses due to runoff. This is taken into account in the model. The amount of crop residue varies for different crops and it varies with yield. Yield is an important factor since higher yields generally produce greater amounts of residue. Consequently, fertilization and good crop management, aimed at increasing yield, are also important for erosion control. Typical crop residue figures for the study area are: corn, 56 lbs/bushel; soybeans, 80 lbs/bushel; wheat, 100 lbs/bushel; and double-crop soybeans, 45 lbs/bushel.

5.1.2.1.3 Effect of Tillage on Erosion. The model takes into account the degree of mechanical erosion control obtained by tillage or special measures such as terracing. Proper tillage systems reduce erosion mechanically by reducing the velocity of the runoff on land with steep slopes. The velocity reduction may be achieved by modifying the surface roughness, the land slope or the land contours. Examples are tillage without regard for slope, usually referred to as vertical cultivation, contour cultivation, contouring, strip cropping, and terracing. Although terracing and contouring are good mechanical control practices, Setia and Johnson (1988) found that they are not cost-effective for the area studied in this thesis. Strip cropping is an effective method for large farms on gentle slopes (Hudson, 1995).

The study area is small and the slope ranges from 1% to 23%. For these reasons only two mechanical erosion control systems are considered in the present study: vertical cultivation and contour cultivation.

Vertical cultivation (VT) generally reduces the flow velocity because the land surface is made lumpy and irregular. No special machinery is required. It is the most common tillage practice used by farmers, and the least costly. However, it may result in areas in which the furrows follow steep slope lines. For this reason, the method is potentially quite erosive.

With contour cultivation (CN), the flow velocity is reduced by aligning furrows perpendicular to the slope. Plowing, planting and harvesting follow the contours of the hills. The furrows tend to hold the water, which increases soil moisture and reduces sediment delivery. The method works best for reducing erosion caused by low to medium rain storms. In large storms, furrows may overflow and the contoured rows may be washed out. This technique is mostly effective for slopes ranging from three to eight percent (Illinois Agronomy Handbook, 1982).

5.1.2.2 Available Data for the SEDEC Model

5.1.2.2.1 Rainfall Erosivity Factor. The rainfall erosivity factor (*R*) is used in the USLE to estimate erosion. Wu (1986) calculated the monthly total, monthly maximum, and the annual rainfall erosivity factors for this watershed based on the hourly rainfall data at Bellevile, Illinois from 1949-1983. These data are used in this research. They are listed in Table 5.3.

5.1.2.2.2 Soil Formations. There are thirteen named soil formations in the selected study area. They are listed in Table 5.4. Each soil formation is identified by soil name or soil series number. A particular soil is further characterized by slope classification and erosion state. An example of a particular soil formation is Hickory, soil series 8, with slope class E and erosion state 3. To use the SEDEC model, the following additional information is required for each soil formation: the crop rotation, the steepness of the slope in percentage, the length of the slope, the cropping and management factor (*C*), the soil erodibility factor (*K*), the bulk density for soil horizons A and B, the depth of soil horizons A and B, and the yield of each crop for different stages of soil depth depletion. The data that describe the soil formations and the cropping techniques were obtained from the Madison County Soil Survey and produced by the SCS (Soil Conservation Service, 1986). The information pertaining to this watershed was published by Setia (1985) and Wu (1986), and is listed in Tables 5.5 to 5.7.

5.1.2.2.3 The Cropping and Management Factors. As explained earlier, the cropping and management factor *C* is a factor that relates soil erosion to the amount of crop residue available. *C* depends on the phase of the crop growth. Values for each combination of crop rotation and tillage system are listed in Table 5.5. For example, the *C* factor for crop rotation CS with FP tillage system and a total residue of 100.000 lb/acre is 0.410. A detailed calculation of *C* values is given by Wischmeier and Smith (1978). The rotation average *C* value for a crop growth phase is the average of the *C* values for all crops in the rotation. The rotation average *C* values vary from 0.004 for COVER to 0.410 for the combination of CS crop rotation and FP tillage system.

5.1.2.2.4 The Soil Erodibility Factor. Some soils are more susceptible to erosion than others. This difference is reflected in the *K* factor and referred to as soil erodibility. The soil erodibility factors *K* for each soil formation are listed in Table 5.6 for both soil horizons A and B. Soil erodibility must be distinguished from actual soil erosion. The actual erosion in the soil loss equation is influenced by slope, rainstorm characteristics, cover, and management as well as by inherent properties of the soil. In this case study, the *K* factor varies between 0.28 and 0.43 for both soil horizon A and soil horizon B. The bulk density is required to convert soil eroded to volume or to depth of soil depleted. The bulk density ranges from 1.25 gr/cm^3 to 1.53 gr/cm^3 for soil horizon A and from 1.33 gr/cm^3 to 1.60 gr/cm^3 for soil horizon B.

5.1.2.2.5 Crop Yield. Using the SEDEC model requires an estimation of crop yield for four stages of erosion with each soil formation. The four stages are: the uneroded phase; the moderately eroded phase; the severely eroded phase; and the very severely eroded phase. These phases are described in Section 3.3.2. Five crops varieties are considered. Linear interpolation between yield and depth of soil eroded is used to estimate productivity for a given soil under these four phases. Data for crop yield for the four erosion stages for each soil formation are listed in Table 5.7.

5.1.2.2.6 Crop Prices and Cost of Management. The data for crop prices and cost of management were based on the monthly average nominal prices reported in the Illinois Agricultural Statistical-Annual Summary for the years 1980 to 1983 (Illinois Cooperative Crop Reporting Service, 1984). Typical figures are: corn, $2.75/bushel; soybeans, $6.73/bushel; meadow, $50.00/ton; and wheat, $3.66/bushel. The cost associated with the different management practices is listed in Table 5.8.

5.1.2.3 Planning Horizon and Discount Rate

For each management policy that was examined, erosion and sedimentation are simulated for a planning horizon of 50 years. The discount rate used in this study is 8%. A fixed discount rate is used because Harshbarger and Swanson (1964); Setia and Johnson (1988); and Johnson et al. (1984) show that, while different discount rates affect present values for various management practices in SEDEC, they do not influence the relative ranking of management practices significantly.

5.1.3 Stochastic Analysis of the Data

Uncertainty Analysis requires quantification of the uncertainty in the input parameters. In this section the input parameters that are stochastic in nature are identified and the appropriate type of probability distribution is determined. Consideration is also given to the correlation between these input parameters which expresses the statistical relationship that must be maintained in modelling.

5.1.3.1 Stochastic Input Parameters

The USLE and the economic analysis both use uncertain input parameters. In the USLE, the *R* factor is a stochastic parameter since it depends on the rainfall. It is the only stochastic parameter in the USLE. The *LS* term can be determined from the topography data, the *C* factor and the *P* factor are determined by the management practices, and the *K* factor depends on the soil formation which can be obtained from the field data.

The uncertain parameters in the economic part of the analysis are: interest rate, production cost, crop yield, and crop prices. As explained earlier, the interest rate for the study was fixed at 8%. The production cost is fully determined by the crop grown and the management practice decided upon. It is therefore not a random variable either. Crop yields are stochastic variables because of unpredictable weather, possible disease and insect infestation, and erosion. Crop prices are also considered to be stochastic variables because crop prices are determined by changing market forces.

Data for the analysis of the rainfall erosivity factor *R* for the case study were obtained from Wu (1986) which provided monthly *R* factors from 1949 to 1983. A goodness of fit test confirmed that the rainfall erosivity follows a log-normal probability distribution. This result agrees with the findings of Wischmeier and Smith (1978) who investigated the distribution of the *R* values for several U.S. watersheds. The distribution for the study area is shown in Figure 5.1. The log-normal distribution was used for generating random values of *R*.

To obtain the type of probability distribution for crop yield and crop prices, the study by Setia (1985) for this watershed was consulted. He found that the crop yield is normally distributed and that crop prices are log-normally distributed. The values of the mean and the standard deviation for the crop yields were determined for each crop and each soil formation from available field data (Setia, 1985). This information was used in the Monte Carlo Simulation.

5.1.3.2 Correlation of Input Data

A correlation analysis was conducted to determine whether the *R* factor, the crop yields, and the crop prices are correlated. The results are presented in Table 5.9. They show that the correlations between the *R* factor, the crop yields, and the crop prices are low. This requires some explanation.

The *R* factor in the USLE, which is a function of the rainfall, is evidently not affected either by crop yield or by crop price. The crop yield, however, does depend on rainfall directly as well as indirectly because rainfall affects soil erosion. The reason why crop yield nevertheless did not show a significant correlation to rainfall for this case study is the way moisture conditions affect crop yield, and the way rainfall affects soil erosion. Regarding the effect of rainfall on crop yield, there is of course a relationship in the sense that adequate moisture is needed for a maximum crop yield. However, once this amount of moisture is available additional rain will not increase the yield. Indeed, excessive rain and severe storms may result in crop damage. Moreover, the time of rainfall is more important than the total amount, since the moisture requirements depend on the stage of crops development. It is therefore not surprising that no significant correlation was observed between total rainfall and crop yield.

Regarding the impact of soil erosion on crop yield, it is true that the *R* factor may impact soil loss considerably in the USLE, and that soil loss may decrease crop yield. However, for this case study, for all soil formations considered, there was no significant decrease in crop yield until the erosion reached the severely eroded soil depth stage, which occurred rarely or not at all.

The following comments may be made regarding the correlation between crop prices and the *R* factor and the correlation between crop prices and crop yield. Crop prices do not depend directly on rainfall, erosion, or sedimentation. Crop prices are to some degree influenced by crop yield. This, however, is due to market forces that operate on the national or international level. In other words, crop prices are determined at the macro level, while the crop yield that is of interest in this study is determined at the micro level. While crop selection, and therefore crop yield, may be affected by crop prices, variation in crop yield occurs mainly because of physical, biological, and environmental factors. Thus, a low correlation between crop prices and crop yields is to be expected.

It was concluded that the three random parameters in the SEDEC model, the *R* factor, crop yield, and crop prices, may be considered independent from each other for this case study. For other case studies, this assumption may not be true. A significant correlation between crop prices and crop yields may occur if the watershed produces a large portion of a particular crop in a country. Correlation between crop yields and the *R* factor may also occur if the eroded soil significantly affects crop yield at the early stages of the soil loss. When correlation is present, the simulation should aim at preserving the statistical relationship between the variables.

5.2 Description of the Application of the Methods of Analysis

This section describes the identification of robust management alternatives for the Highland Silver Lake Watershed. It starts with a listing of the management policies studied, together with sediment constraints, erosion limits, and tax charges considered in the analysis. Together these determine the number of sets of management practices to be used in the optimization.

The section then describes how optimum sets of management practices were developed, using the available data as deterministic input. Following this the section describes how uncertainty analysis was used a) to identify the management policies that are robust to uncertainty in the input parameters, b) to determine which input parameters are important for the modelling of erosion and sedimentation, and c) to identify the robust set of management practices.

5.2.1 Management Decisions

5.2.1.1 Management Policies

Three management policies were examined, the Least Cost policy, the Erosion Tax policy and the Erosion Standard policy. The Least Cost policy is based on the watershed as a whole, i.e., the goal here is to maximize total revenue or to minimize the total Relative Revenue Reduction (RRR) while meeting sediment criteria at the end point of the watershed. The Erosion Standard policy requires erosion criteria to be met at the farm level, i.e., the goal here is to maximize farm income while meeting a limitation on erosion from each field. For the Erosion Tax policy both the entire watershed and the individual farms must be considered, i.e., the goal here is to minimize RRR, which means maximizing farm income, while imposing tax charges on each farm for any amount of erosion above a predetermined level.

5.2.1.2 Pollution Constraints

Two pollution constraints were used, namely, erosion rates of 1 ton/acre/annum and of 3 tons/acre/annum. Using the deterministic input data, an erosion constraint of 1 ton/acre/annum under the Erosion Standard policy corresponds to a total sediment load of 48 tons/annum under the Least Cost policy, and it corresponds to a tax charge of $11.00 for each ton of erosion under the Erosion Tax policy. An erosion constraint of 3 tons/acre/annum under the Erosion Standard policy corresponds to a total sediment load of 262 tons/annum under the Least Cost policy, and a tax charge of $2.00 for each ton of erosion under the Erosion Tax policy. The case of no sediment constraint was also analyzed for the Least Cost policy to obtain a basis for comparing costs of pollution control. Thus, seven sets of optimal management practices were to be derived which represent the range of region-wide policy decisions that must be considered.

5.2.2 Optimum Management for Deterministic Input

5.2.2.1 Least Cost Policy

Using the SOILEC module, the erosion and the revenue are calculated for 30 combinations of management practices (combinations of five crop rotations, three tillage systems and two mechanical erosion controls) for each LMU for a period of 50 years and a discount rate of 8%.

As soil is eroded, the crop yield decreases. The new soil depth must therefore be estimated at the end of every year and the associated change in crop yield used for the next year. Although some studies indicate that the relationship between crop yield and soil depth is non-linear, it was difficult to obtain enough information to define the relationship accurately. In the SOILEC module, the relationship between crop yield and soil depth was therefore assumed to be linear between erosion stages. Figure 5.2 shows an example of the relationship between the corn yield and soil depth for soil formation Sable 68A1. Using the S-PGEN module, the sediment yield and the total RRR are determined for each Transect. Using the OPT module, the optimal solution is determined for the three degrees of constraint on total sediment. The results are presented in the form of a graph that shows possible trade-offs between total sediment load and the total RRR for the entire watershed for sediment loads up to 262 tons/annum. In addition, tables of optimum management practices are given for the three sediment constraints, the unconstrained case, and the cases with a constraint of 262 and 48 tons/annum, respectively.

5.2.2.2 Erosion Tax Policy

With the Erosion Tax policy alternative, a program called ADDTAX is used after the SOILEC module to adjust the net revenue ranking of the management practice for each LMU. Input into the ADDTAX model is the output of SOILEC and the tax charge. ADDTAX estimates the net revenue for a given erosion tax constraint, and then ranks the management practices based on revenue. The output of ADDTAX is then run through the S-PGEN and OPT modules to obtain a set of management practices for the entire watershed that gives the minimum total RRR or the least cost to the farmer of meeting the pertinent sediment constraint. The results are presented in the form of a graph that shows possible trade-offs between total sediment load and the total RRR for the entire watershed for the sediment loads resulting from an erosion tax of up to \$11.00/ton. In addition, tables of optimum management practices are given for the two erosion taxes, \$2.00/ton to \$11.00/ton.

5.2.2.3 Erosion Standard Policy

To apply the Erosion Standard policy, a program called SCREEN is developed in this study to screen the SOILEC results that fulfill the erosion limitation. The output of SCREEN is then run through the S-PGEN and OPT modules to obtain the set of management practices for the entire watershed that gives the optimal solution. The results are presented in the form of a graph that shows possible trade-offs between total sediment load and the corresponding total RRR for the entire watershed for the range of sediment loads resulting from an erosion standard up to 3 tons/acre/annum. In addition, tables of optimum management practices are given for the two erosion constraints, 3 tons/acre/annum and 1 ton/acre/annum.

5.2.3 Sensitivity of Management Policies

5.2.3.1 Parameter Uncertainty

The parameters in the SEDEC model that are considered to be uncertain are:

1) the rainfall erosivity factor (R);

2) the yield production per unit area for five variety of crops for each of thirteen soil formations, Y_{ch} for corn, Y_{sh} for soybeans, Y_{wh} for wheat, and Y_{dh} for double-crop-soybeans, and Y_{mh} for meadow, where h denotes the soil formation; and

3) the crop prices for three variety of crops, PR_c for corn, PR_s for soybeans, and PR_w for wheat, and the revenue for pasture, PR_m. The price of double-crop-soybeans is considered to be the same as the price of soybeans, while the yield and price of cover are zero.

5.2.3.2 Monte Carlo Simulation

Monte Carlo Simulation is used to evaluate the sensitivity of the policies to uncertain model input. Since crop yields for the five crops vary for the thirteen soil formations, a total of 70 parameters are considered uncertain. Random values for these 70 parameters are generated in the Monte Carlo Simulation for use in the SEDEC model.

An additional program called MCSED was developed for this research to incorporate the random number generation into the SEDEC model. The results of MCSED are entered into the S-PGEN and OPT modules. For each Monte Carlo realization, the total RRR for maintaining a stream sediment load under each of the three policies is determined for a range of sediment loads up to

262 tons/annum. Under the Erosion Tax policy, a range of tax charges up to $11.00 is imposed on each farm for each ton of erosion. Under the Erosion Standard policy, an erosion standard varying from 0.2 tons/acre/annum up to 3 tons/acre/annum is used.

5.2.3.2.1 Required Number of Monte Carlo Simulations. Simulations are added until the results become stable and additional realizations cause no important change in the results. This was done qualitatively by eye examination upto three decimal. Under the Least Cost policy and Erosion Tax policy, 800, 1000, 1200, 1400, and 1600 Monte Carlo realizations were obtained to determine the adequate number of simulations. It was found that for this problem no important change in the mean net return and the variance occurs after 1200 realizations. Under the Erosion Standard policy, 200, 300, 400, 500, and 600 Monte Carlo realizations were obtained for each 0.2 tons/acre/annum interval in the erosion standard. No important change in the mean net return and the variance occurred after 400 realizations.

5.2.3.2.2 Output of Monte Carlo Simulations. For each management policy, the trade-off between the stream sediment load maintained and the total RRR is determined. The sensitivity of the model output due to uncertainty in the input parameters can be estimated by analyzing the distribution of total RRR under each sediment load constraint for each policy as determined from the Monte Carlo Simulation results. The mean and the 90% confidence limits of the total RRR for each sediment load for each management policy is calculated.

5.2.4 Parameter Identification

5.2.4.1 Modified Generalized Sensitivity Analysis

The Modified Generalized Sensitivity Analysis for nonpoint source water quality management was used to determine the important model parameters in the SEDEC model for managing sediment in the Highland Silver Lake Watershed. Twelve hundred realizations of the required 70 parameter values in the SEDEC model were randomly generated in the Monte Carlo Simulations. The results were then placed into two categories, the Behaviour and the Non-Behaviour categories. The classification algorithm for the linked process of nonpoint source simulation and optimization is based on a comparison with the results from the deterministic study.

The Modified Generalized Sensitivity Analysis is applied to the watershed as a whole and to the individual farm units under each of the three management policies. For the watershed as a whole, a Monte Carlo realization is placed in the Behaviour category if the total sediment load is less than 110% of the deterministic total sediment load and the total revenue is greater than 90% of the maximum total revenue based on the deterministic case. Outside these limitations, the results are considered to be in the Non-Behaviour category. This classification will be referred to as the Watershed based classification.

When individual farms are considered separately, a Monte Carlo realization is placed in the Behaviour category if the erosion rate in the farm field is less than 110% of the deterministic erosion rate and the revenue is greater than 90% of the maximum revenue based on the deterministic case for each field (LMU). Outside these limitations, the results are considered to be in the Non-Behaviour category. This classification will be referred to as the Farm based classification.

Once the model output is divided into Behaviour and Non-Behaviour categories, the CDFs of each corresponding input parameter for the two categories can be obtained for each management policy under consideration. In this study, pairs of CDFs are developed for the rainfall erosivity R, the yields of five crop types for the thirteen soil formations and the crop prices for four crops. The Kolmogorov-Smirnov two sample statistic tests (K-S test) is used to investigate the significance of each parameter as described in Section 4.2.3. In this study, the sensitivity index is developed with reference to the 90% confidence level.

The results will be presented in the next chapter in the form of tables of sensitivity indices for the 70 parameters in the SEDEC model. For the Watershed based management analysis, there are five tables of sensitivity indices. The first three tables are results using the three sediment constraints under the Least Cost policy and the last two tables are results using the two tax levels under the Erosion Tax policy. The sensitivity indices are listed for each LMU. For the Farm based analysis, four tables of sensitivity indices will be produced in Chapter 6. The first two are the results using the two erosion constraints under the Erosion Standard policy, and the other two tables are the sensitivity indices using the two tax charges under the Erosion Tax policy. In the Farm based management analysis, the sensitivity indices are the same for each LMU with the same soil formations. However, the sensitivity indices are also listed for each LMU to be comparable with the Watershed based information.

5.2.5 Regret and Robustness Analyses

Regret and Robustness Analyses are used to obtain from the SEDEC model a set of management practices that is likely to be acceptable under uncertain future conditions. The Analyses are applied to identify such management practices for the watershed as a whole and also for individual farm (LMU). Only the Least Cost policy is considered for the analysis based on the watershed as a whole and only the Erosion Standard policy is considered for the analysis based on each individual farm.

One-hundred Monte Carlo realizations of the required 70 parameter values in the SEDEC model are randomly generated in the Monte Carlo Simulations. These realizations result in one-hundred optimal sets of management practices for the entire watershed for the watershed basis, and one-hundred optimal sets of management practices for each LMU for each individual farm. The decision to limit the Monte Carlo simulations to one-hundred was based on adding simulations until the results became stable and showed no important further change.

For the watershed as a whole, the definition of regret for a given input scenario and a given management solution is the difference between the total revenue or total sediment for the entire watershed for this management solution and for the optimal design for this input scenario. For each individual farm, the definition of regret for a given input scenario and a given management solution is the difference between the revenue or erosion at each LMU for the optimal set of management practices for the given input scenario and the revenue or erosion actually obtained. The procedure of obtaining the robust set of management practices using the Regret Analysis is as described in Section 4.3.

The Robustness Analysis requires specific revenue and sediment limits that one wants to attain. For the entire Watershed basis, three revenue limits and three sediment limits were established. The revenue limits are a minimum total revenue of 95%, 90%, and 85% of the maximum revenue based on the optimal set of management decision. The sediment limits are a maximum total sediment of 200 tons/annum, 150 tons/annum, and 100 tons/annum. For the individual Farm basis, three revenue limits and three erosion limits were established. The farm revenue limits are a minimum total revenue of 95%, 90%, and 85% of the maximum revenue obtained from the optimal set of management practices. The erosion limits are a maximum erosion of 2 tons/acre/annum, 1.5 tons/acre/annum, and 1 ton/acre/annum.

For the analysis based on the entire watershed, the results of the Regret and Robustness Analyses are presented in the form of tables listing the maximum revenue regret, the expected revenue regret, the maximum sediment regret, the expected sediment regret, and the frequency of meeting the three revenue and sediment limits. The end results are presented in the form of a table that shows the robust set of management practices for the entire watershed.

For the analysis based on the individual farm, the results of the Regret and Robustness Analyses are presented in the form of tables showing the maximum revenue regret, the expected revenue regret, the maximum erosion regret, the expected erosion regret, and the frequency of meeting the three revenue and erosion limits. The end results are presented in the form of tables that show robust management practices for individual farms.

Figure 5.1 Log-Normal Probability Plot of Rainfall Erosivity for the Highland Silver Lake Watershed Based on Annual Rainfall Erosivity (Wu, 1986)

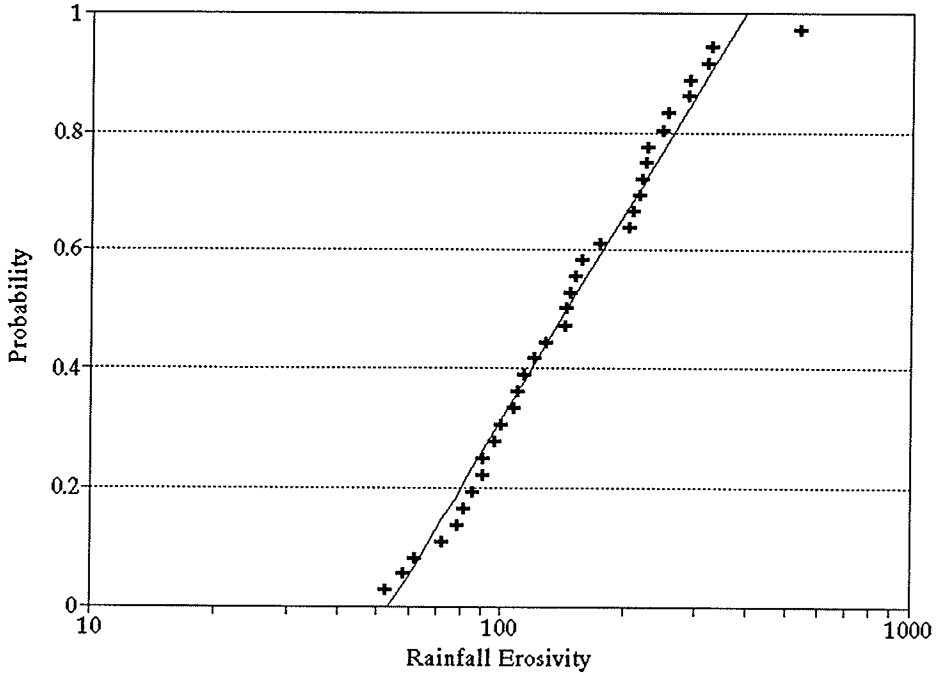


Figure 5.2 An Example of the Relationship between the Corn Yield and Soil Depth for Soil Formation Sable 68A1.

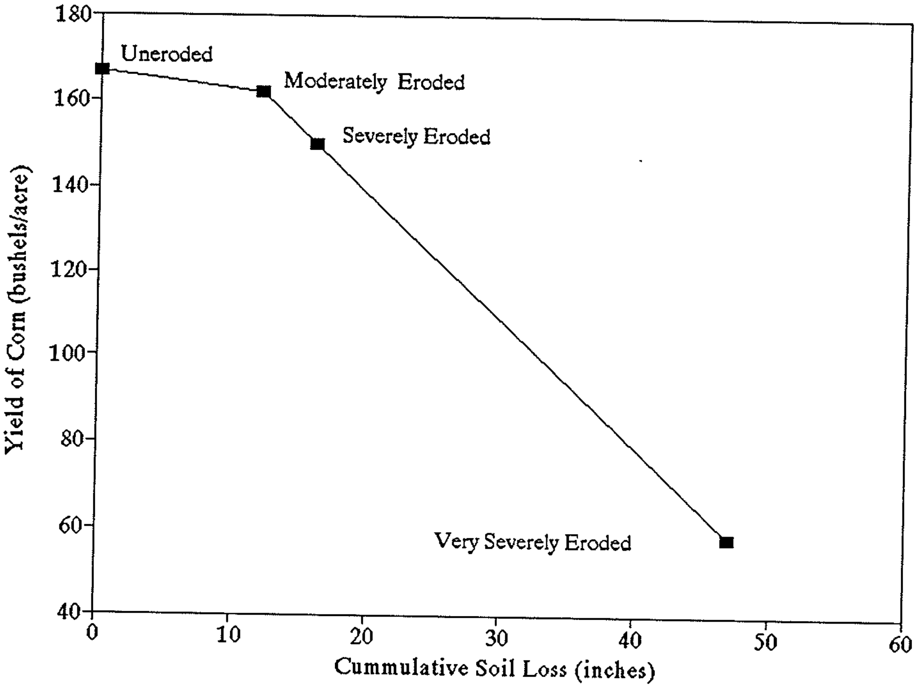


Table 5.1 List of Transects, LMUs, and Their Descriptions for the Highland Silver Lake Watershed

Transect No.	LMU	Soil Formation	Area (acres)	Slope (%)	Slope-length (ft)
1	1	Atlas-Grantfork 914D3	5.58	13	120.0
	2	Marine 517B1	2.97	4	200.0
2	1	Orion 415A1	7.70	1	200.0
	2	Atlas-Grantfork 914D3	3.20	13	120.0
3	1	Atlas-Grantfork 914D3	3.80	13	120.0
	2	Marine 517B1	2.70	4	200.0
4	1	Orion 415A1/Lawson 451A1	3.00	1.4	182.5
	2	Atlas-Grantfork 914D3	2.60	13	120.0
5	1	Orion 415A1/Lawson 451A1	4.00	1.4	182.5
	2	Orion 415A1	13.00	1	200.0
	3	Hickory 8E3	4.41	23	75.0
6	1	Orion 415A1/Lawson 451A1	1.00	1.4	182.5
	2	Orion 415A1	8.67	1	200.0
	3	Atlas-Grantfork 914D3	3.63	13	120.0
7	1	Orion 415A1	8.89	1	200.0
8	1	Orion 415A1	8.86	1	200.0
	2	Atlas-Grantfork 914D3	2.31	13	120.0
	3	Elco 119C3	1.34	7.5	200.0
9	1	Orion 415A1	8.89	1	200.0
	2	Atlas-Grantfork 914D3	2.77	13	120.0
	3	Marine 517B1	15.69	4	200.0
10	1	Atlas-Grantfork 914D3	2.81	13	120.0
11	1	Lawson 451A1	16.07	2	150.0
	2	Darmstadt 620C3	2.78	6	150.0
12	1	Darmstadt 620C3/914C3	5.75	6.3	150.0
	2	Cowden-Piasa 993A1/Herrick-Piasa 995A1	22.94	1	300.0
13	1	Darmstadt 620C3	11.48	6	150.0
	2	Darmstadt-Oconee 916B1	16.60	2.5	300.0
	3	Huey 120A1/Herrick-Piasa 995A1	11.10	1	291.0
14	1	Darmstadt 620C3	1.27	6	150.0
	2	Darmstadt 620C3	3.85	6	150.0
	3	Darmstadt-Oconee 916B1	2.50	2.5	300.0
15	1	Sable 68A1/Herrick-Piasa 995A1	21.40	1	260.0
	2	Darmstadt-Oconee 916B1	5.20	2.5	300.0
16	1	Atlas-Grantfork 914D3	3.55	13	120.0
	2	Marine 517B1	10.54	4	200.0
	3	Darmstadt 620C3	4.43	6	150.0

Table 5.2 Alternative Management Practices for the Highland Silver Lake Watershed

Crop Rotation	Tillage Systems	Mechanical Control
Corn-Soybeans (CS)	Fall Plowing (FP)	Vertical Cultivation (VT)
Corn-Soybeans-Wheat-Double-Crop-Soybeans (CSWDCS)	Conventional Tillage (CT)	Contour Cultivation (CN)
Corn-Soybeans-Wheat-Meadow (CSWM)	No-Till (NT)	
Corn-Corn-Soybeans-Wheat-Meadow-Meadow-Meadow-Meadow (CCSWMMMM)		
Continuous Cover (COVER)		

Table 5.3 Rainfall Erosivity, *R*, for the Highland Silver Lake Watershed

Year	Rainfall Erosivity
1949	96.49
1950	107.81
1951	52.29
1952	61.58
1953	57.79
1954	152.43
1955	113.94
1956	325.38
1957	532.30
1958	286.19
1959	148.06
1960	100.12
1961	318.12
1962	90.63
1963	81.41
1964	72.14
1965	217.23
1966	90.62
1967	120.77
1968	225.34
1969	287.48
1970	144.37
1971	77.94
1972	254.94
1973	228.16
1974	209.99
1975	128.69
1976	85.73
1977	174.37
1978	110.38
1979	248.04
1980	143.90
1981	204.60
1982	220.47
1983	157.80

Table 5.4 Soil Formations in the Highland Silver Lake Watershed

Soil Name	Soil Series	Slope Class	Erosion State
Hickory	8	E	3
Sable	68	A	1
Elco	119	C	3
Huey	120	A	1
Orion	415	A	1
Lawson	451	A	1
Marine	517	B	1
Darmstadt	620	C	3
Atlas-Grantfork	914	C	3
Atlas-Grantfork	914	D	3
Darmstadt-Oconee	916	B	1
Cowden-Piasa	993	A	1
Herrick-Piasa	995	A	1

Table 5.5 The *C* Average Values for Various Total Residue and Management Alternatives for Estimating Soil Erosion using the USLE for the Highland Silver Lake Watershed

Crop Rotation	Tillage	Total Residue (lb/acre)				
		1000.000	2000.000	3000.000	4000.000	>4000.000
CS	FP	0.410	0.410	0.410	0.410	0.410
CSWDCSB	FP	0.306	0.306	0.306	0.306	0.306
CSWM	FP	0.166	0.166	0.166	0.166	0.166
CCSWMMMM	FP	0.130	0.130	0.130	0.130	0.130
COVER	FP	0.004	0.004	0.004	0.004	0.004
CS	CT	0.274	0.155	0.105	0.075	0.050
CSWDCSB	CT	0.220	0.152	0.110	0.100	0.075
CSWM	CT	0.107	0.071	0.067	0.057	0.045
CCSWMMMM	CT	0.077	0.052	0.033	0.022	0.016
COVER	CT	0.004	0.004	0.004	0.004	0.004
CS	NT	0.219	0.105	0.060	0.043	0.030
CSWDCSB	NT	0.153	0.073	0.047	0.033	0.027
CSWM	NT	0.176	0.095	0.062	0.057	0.045
CCSWMMMM	NT	0.051	0.039	0.029	0.019	0.014
CCSWMMMM	NT	0.004	0.004	0.004	0.004	0.004

Table 5.6 *K* factors and Bulk Density for Soil Horizons A and B in the Highland Silver Lake Watershed

Soil Formations *)	**K factors**		**Bulk Density (gr/cm^3)**	
	Soil Depth A	Soil Depth B	Soil Depth A	Soil Depth B
Hickory 8 E3	0.37	0.37	1.53	1.55
Sable 68A1	0.28	0.28	1.30	1.40
Elco 119C3	0.37	0.37	1.40	1.50
Huey 120A1	0.43	0.43	1.40	1.50
Orion 415 A1	0.37	0.37	1.25	1.33
Lawson 451A1	0.32	0.43	1.30	1.50
Marine 517B1	0.37	0.37	1.40	1.50
Darmstadt 620C3	0.43	0.43	1.40	1.50
Atlas-Grantfork 914C3	0.43	0.43	1.50	1.60
Atlas-Grantfork 914D3	0.43	0.43	1.50	1.60
Darmstadt-Oconee 916B1	0.39	0.43	1.40	1.50
Cowden-Piasa 993A1	0.37	0.37	1.30	1.40
Herrick-Piasa 995A1	0.32	0.34	1.30	1.40

Table 5.7 Crop Yields for the Highland Silver Lake Watershed

Soil Formations *)	**Soil Depth (m)**	**Corn (bu/acre)**	**Soybeans (bu/acre)**	**Wheat (bu/acre)**	**Double Crop Soybeans (bu/acre)**	**Meadow (ton/acre)**
Hickory 8E3	0	49.000	16.600	22.800	10.000	2.100
	5	41.000	13.900	19.200	8.400	1.800
	9	38.700	13.100	18.000	7.900	1.700
	58	33.800	11.500	15.700	6.500	1.400
Sable 68A1	0	167.000	60.000	77.000	36.000	5.600
	12	162.200	58.200	74.700	34.900	5.400
	16	150.300	54.000	69.300	32.000	5.000
	47	58.000	17.000	18.000	10.200	2.000
Elco 119C3	0	80.000	29.000	46.000	17.400	3.800
	2	76.000	27.600	43.700	16.500	3.600
	6	72.000	26.100	41.400	15.700	3.400
	62	48.000	14.000	17.000	8.400	1.800
Huey 120A1	0	52.000	21.000	37.000	12.600	2.600
	5	50.400	20.400	35.900	12.200	2.500
	9	46.800	18.900	33.300	11.300	2.300
	37	38.000	17.000	18.000	10.200	2.000
Orion 415A1	0	111.000	40.000	59.000	24.000	4.700
	3	107.700	38.800	57.200	23.300	4.600
	7	99.000	36.000	53.100	21.600	4.200
	60	58.000	17.000	18.000	10.200	2.000
Lawson 451A1	0	161.000	48.000	62.000	28.800	5.700
	5	156.200	46.600	60.100	28.000	5.500
	9	144.900	43.200	55.800	25.900	5.100
	60	58.000	18.000	17.000	10.200	2.000
Marine 517B1	0	97.000	34.000	57.000	21.000	4.800
	8	94.100	33.000	55.300	19.800	4.700
	14	87.200	30.600	51.200	18.800	4.300
	57	58.000	17.000	18.000	10.200	2.000

Table 5.7 Crop Yields for the Highland Silver Lake Watershed (Continued)

Soil Formations *)	**Soil Depth (m)**	**Corn (bu/acre)**	**Soybeans (bu/acre)**	**Wheat (bu/acre)**	**Double Crop Soybeans (bu/acre)**	**Meadow (ton/acre)**
Darmstadt 620C3	0	41.400	17.200	28.800	10.300	2.200
	2	39.330	16.340	27.360	9.790	2.090
	6	37.260	15.480	25.920	9.270	3.100
	46	33.120	13.760	23.040	8.240	1.760
Atlas-Grantfork 914C3	0	50.000	12.700	18.600	7.600	2.100
	2	46.000	11.700	17.100	7.000	1.900
	6	34.300	8.700	12.800	5.200	1.700
	61	20.000	5.000	10.000	3.000	1.000
Atlas-Grantfork 914D3	0	32.300	11.800	16.700	7.100	1.600
	2	29.100	10.600	15.000	6.400	1.400
	6	27.500	10.000	14.200	6.000	1.300
	61	20.000	5.000	10.000	3.000	1.000
Darmstadt-Oconee 916B1	0	77.000	28.000	48.000	16.800	3.800
	5	73.100	26.600	45.600	16.000	3.600
	9	61.400	22.300	38.300	13.400	3.000
	60	58.000	17.000	18.000	10.200	2.000
Cowden-Piasa 993A1	0	106.000	37.000	59.000	22.200	4.100
	13	102.800	35.900	57.200	21.500	4.000
	17	95.400	33.300	53.100	20.000	3.700
	60	58.000	17.000	18.000	10.200	2.000
Herrick-Piasa 995A1	0	125.000	44.000	64.000	26.000	4.500
	13	121.300	42.700	62.100	25.600	4.400
	17	112.500	39.600	57.600	23.800	4.100
	60	58.000	17.000	18.000	10.000	2.000

*) The numbers are from Table 5.4

Table 5.8 Cost of Management Practices for the Highland Silver Lake Watershed

Crop Rotation	Tillage	Cost ($/bu)
CS	FP	133.59
CSWDCSB	FP	152.92
CSWM	FP	112.32
CCSWMMMM	FP	133.41
COVER	FP	0.00
CS	CT	126.28
CSWDCSB	CT	147.18
CSWM	CT	106.70
CCSWMMMM	CT	129.93
COVER	CT	0.00
CS	NT	126.02
CSWDCSB	NT	145.58
CSWM	NT	108.94
CCSWMMMM	NT	131.25
COVER	NT	0.00

Table 5.9 Correlation among Input Parameters for the Highland Silver Lake Watershed

	***R* factor**	**Yields**				**Prices**			
		Corn	Soybeans	Wheat	Meadow	Corn	Soybeans	Wheat	Meadow
R factor	1								
Yield Corn	-0.24	1							
Yield Soybeans	0.05	0.44	1						
Yield Wheat	-0.36	-0.08	-0.15	1					
Yield Meadow	0.21	-0.23	-0.33	0.39	1				
Price Corn	0.04	-0.49	-0.28	0.08	0.39	1			
Price Soybeans	-0.43	0.41	-0.38	0.51	0.25	0.20	1		
Price Wheat	0.18	-0.36	-0.09	0.33	0.23	0.41	-0.26	1	
Price Meadow	-0.48	0.47	0.13	0.47	0.17	0.12	0.36	-0.37	1

CHAPTER 6

CASE STUDY - RESULTS

This chapter presents the results of the application of the described uncertainty analyses to the Highland Silver Lake Watershed in Illinois. The first section describes the results of the three management policies using the deterministic set of input data in the simulation and optimization model, SEDEC. The second section discusses the results of the uncertainty analyses.

6.1 Optimum Management for Deterministic Input

Optimum management practices were determined by simulation and optimization based on deterministic input data for the Least Cost policy, the Erosion Tax policy, and the Erosion Standard policy. The results are shown in Tables 6.1 to 6.8. Tables 6.1 to 6.7 show the management practices selected at each LMU under the various management policies and pollution standards. Table 6.8 summarizes the changes in crop rotations, tillage systems, and mechanical erosion control that are needed under each policy compared to the situation in which there is no constraint on sediment. It also lists the total Relative Revenue Reductions (RRR).

Tables 6.1 to 6.7 show that for all erosion control strategies, the LMUs with a land slope of 13% or more have high erosion rates and are not suitable (i.e., too expensive) for raising any crop. For this reason COVER is chosen even when no erosion control is imposed. A total of 10 LMUs with a total area of 34.7 acres are in this category. The remaining LMUs are considered crop land.

For the case of no constraints on erosion, the results of the study (Table 6.1) indicate VT to be adequate as a mechanical erosion control practice and CT to be used as a tillage system for all crop land. The results for this case also show that a crop rotation of CSWDCS is indicated for those lands having a slope less than 6%, except for $LMU_{11\,1}$. $LMU_{11\,1}$ has a slope of 2% and indicates CS as the preferred crop rotation. LMUs with a land slope of 6% and 6.3% indicates CSWM as the preferred crop rotation, while $LMU_{8\,3}$ with a slope of 7.5% indicates CSWDCS as the crop rotation. In general, crop rotation CSWM results in less erosion because of the use of Meadow in the rotation. For the unconstrained sediment case, this optimal set of management practices results in a total revenue of $33,071.00/annum and a total sediment load of 412 tons/annum. In the remainder of this section, revenue and sediment for the three management policies will be compared with this unconstrained case to determine which is best based on the deterministic set of input data.

Tables 6.2 and 6.3 show the least cost (minimum total RRR) management practices for a sediment load limitation of 262 tons/annum and 48 tons/annum, respectively. Under the Least Cost policy and a sediment load limitation of 262 tons/annum, only $LMU_{12\,1}$ is required to change from crop land to COVER, while $LMU_{6\,1}$ is required a change its tillage system from conventional tillage (CT) to no-till (NT). $LMU_{13\,1}$ and $LMU_{14\,1}$, with a total of 9.5% of the crop land area are required to change the mechanical erosion control from vertical cultivation (VT) to contour cultivation(CN). With the more severe restriction on the sediment load, more changes in management practices are required, a total of 51% of the crop land area is required to change management practices. Of this total, 10% must change from crop land to COVER, 41% from CT to NT, and 13.4% from VT to CN. It is important to note that almost all of the required changes occurred in the LMUs adjacent to the stream. This agrees with the studies of Prato and Shi (1990); and Jones et al. (1990). It is expected since under the Least Cost policy these LMUs act as a sediment screen for the upland region. The sediment delivery ratio based on Clarke (1983) assumes that all erosion in the first LMUs is delivered into the stream. Therefore, soil conservation on these LMUs directly affects the total sediment load. For a sediment load limitation of 48 tons/annum, those LMUs having a land slope of 4% or less are required to change the tillage systems or mechanical erosion control practices, while those LMUs having a land slope greater than 4% are required to change from cropland to COVER (see, $LMU_{12\,1}$, $LMU_{13\,1}$, and $LMU_{14\,1}$). This is again to be expected, since these lands produce relatively high erosion rates for sediment that directly enters the stream. A change in tillage system or mechanical erosion control practice would not be enough to meet the sediment limitation or the total RRR would be so high that no gain would be obtained.

The optimum management practices under the Erosion Tax policy with a tax of $2.00/ton are shown in Table 6.4. With this policy, 25.8% of the area is required to change the tillage system from CT to NT and 11.3% of the area is required to change the mechanical erosion control practice from VT to CN. Table 6.5 shows the results when the tax is increased to $11.00/ton. Here almost all LMUs are required to change to NT as the tillage system and 35.4% of the total area is required to change to CN cultivation. Changes in crop rotation are required for LMUs with a land slope of 6% or greater, not only for those adjacent to the stream, but also for the upland LMUs. Under the Erosion Tax policy, the changes in management practice are not dictated by the sediment delivery ratio, but by the trade-off between the amount of erosion that occurs and the RRR of abatement, i.e., the cost analysis at the farm level. The location of the LMU is not an issue.

Under the Erosion Standard policy, the results are shown in Tables 6.6 and 6.7 for the 3 tons/acre and the 1 ton/acre cases, respectively. With an erosion constraint of 3 tons/acre, 28.2% of the total area is required to change the tillage system from CT to NT and 24.8% is required to change the mechanical erosion control practice. For an erosion constraint of 1 ton/acre, 76.5% of the total area requires NT as the tillage system and 33.6% requires CN cultivation. This means that to meet an erosion constraint of 1 ton/acre, management practice must be changed for all crop land by changing either the crop rotations, the tillage systems, or the mechanical erosion control practices. For an erosion constraint of 1 ton/acre, seven LMUs are required to change from cropland to COVER. These are LMU$_{8,3}$, LMU$_{11,2}$, LMU$_{12,1}$, LMU$_{13,1}$, LMU$_{14,1}$, LMU$_{14,2}$, and LMU$_{16,3}$. Under this policy, each LMU is required to meet the erosion limit, therefore, the location of the LMU is not important. All of these LMUs have a land slope greater than or equal to 6%. The Erosion Standard policy requires more changes in tillage systems than the Least Cost policy for both erosion constraints. A comparison with the Erosion Tax policy shows that an erosion standard of 1 ton/acre produces the same results as a tax of $11.00/ton. The only difference occurs in LMU$_{8\ 3}$, which requires COVER under the Erosion Standard policy while a crop can still be grown under the Erosion Tax policy.

Table 6.8 summarizes the changes required by the three management policies for different sediment constraints and the associated total RRRs compared to the unrestricted sediment case. This table shows the percentage changes in management practices throughout the system, the total number of LMUs that are required to change management practices, the number of LMUs adjacent to the stream that are required to change management practices, the percentage of acreage that changes management practices in all LMUs adjacent to the stream and total RRR increases compared to the unrestricted sediment case.

It can be seen that the Least Cost policy requires changes in management practice over a much smaller area than the other two policies. Table 6.8 shows that for sediment load limitations of 262 tons/acre and 48 tons/acre, the percentage of total area that requires changes in management practices under the Least Cost policy is 12.4% and 51%, respectively. The Erosion Standard and the Erosion Tax policy would affect a much larger area. For a sediment load limitation of 262 tons/annum, the total percentage area where changes in management practices would be required under the Erosion Tax policy and under the Erosion Standard policy is 39% and 52.3%, respectively. For a sediment load limitation of 48 tons/annum, these figures are 100% and 98.8%, respectively.

In terms of the location of the LMUs that are required to change management practice, the Least Cost policy shows that for a sediment load limitation of 262 tons/acre, 4 LMUs are required to change. All of those 4 LMUs are located adjacent to the stream. For the same sediment load limitation, 13 LMUs would be required to change management practices under the Erosion Tax policy and 14 LMUs would change under the Erosion Standard policy. Of these LMUs, only 3 LMUs are located adjacent to the stream, $LMU_{12\,1}$, $LMU_{13\,1}$, and $LMU_{14\,1}$. These three LMUs, with slopes of 6%, have high erosion rates. In fact, changes in management practices are required in them under all three management policies. Table 6.8 shows that when the sediment is further limited to 48 tons/acre, 13 LMUs are required to change management practices under the Least Cost policy, 27 LMUs are required to change the management practices under the Erosion Tax policy, and 27 LMUs are required to change the management practices under the Erosion Standard policy. For all three management policies, 12 of the mentioned LMUs are located adjacent to the stream. These twelve include all the crop land which is located adjacent to the stream. With the Least Cost policy, the sediment delivery ratio largely determines the required management practices. It depends on the location of the LMUs. LMUs located adjacent to the stream are important for capturing sediment delivered from upslope LMUs. Under the Erosion Tax policy, changes in management practices are more dependent on the erosion rates and the erosion abatement costs than on the sediment delivery ratio. Under the Erosion Standard policy, the changes are based on the individual erosion rates, therefore, the solution is not sensitive to either the erosion abatement costs or the sediment delivery ratio.

In terms of total reduction in revenue, in other words, total cost of implementing the management practices, the results in Table 6.8 show that the Least Cost policy is the most cost-effective solution for both sediment load limitations. The total cost or the total Relative Revenue Reduction is \$120.00/annum for a sediment load limitation of 262 tons/annum, and \$1,330.00/annum for a sediment load limitation of 48 tons/annum. For the same two sediment limitations, the Erosion Standard policy leads to a total cost of \$919.00/annum and \$3,280.00/annum, respectively. These are the highest costs among the three policies. The Erosion Tax policy lies in between, with a total cost of \$550.00/annum for a sediment load limitation of 262 tons/annum, and \$1,977.00/annum for a sediment load limitation of 48 tons/annum. It may come as a surprise that the total cost figures associated with the implementation of the erosion control policies turn out to be this low. This is in part caused by the fact that those LMUs that tend to produce high erosion rates have relatively small areas compared to the others. One should also keep in mind that the total study area comprises only 289 acres. The cost of erosion control obtained in this study is quite comparable to the results obtained by Miltz et al. (1988) for the same watershed. The ranking of the three management policies in terms of cost for the two sediment load limitations is consistent with the conventional understanding of the cost-effectiveness of the three policies.

6.1.1 Cost-Sediment Relationship under the Three Policies

Possible trade-offs between total sediment and total RRR for the deterministic input under the three policies are shown in Figure 6.1. No administrative costs were incorporated in these data. The figure shows that the Least Cost policy tends to be the most cost-effective approach. For the same restriction on sediment, the Erosion Tax and Erosion Standard policies result in higher RRRs compared to the Least Cost policy. It can be seen that at a sediment load limitation of 35 tons/annum, a crossing occurs between the RRRs of the Erosion Tax and Erosion Standard policy. This indicates that sometimes the Erosion Standard policy can lead to a more cost effective solution. This crossing also occurred at a sediment load limitation of 100 tons/annum for this river basin in a study by Miltz et al. (1988), and at a sediment load limitation of 700 tons/annum for the Long Creek Watershed (Bouzaher et. al., 1990).

The advantage of the Erosion Tax policy is the ability to base the management decisions on differences in marginal abatement costs. Where such differences are low, this advantage becomes less significant. This result is consistent with the finding of Russell (1986); and Miltz et al. (1988). Russell found that the Erosion Tax policy is less cost effective than the Erosion Standard policy if sources having high costs affect the ambient water quality more heavily than those having low costs, unless the differences in effects on water quality are small.

All these conclusions are based on an analysis with fixed input data, that is for a deterministic input scenario. The present study extended previous studies by Russell (1986); and Miltz et al. (1988) by incorporating the effect of uncertainty in the model input. These results are discussed in the following section.

6.2 Effect of Uncertainty on Management Decision

6.2.1 Sensitivity of the Management Policies to Uncertain Input Information

A sensitivity analysis using Monte Carlo Simulation was performed to identify the sensitivity of the three policies to uncertainty in the input parameters. For each realization of the input parameters, the total cost in terms of Relative Revenue Reduction (RRR) of meeting specified restrictions on the stream sediment load was determined for the three policies. This resulted in a large number of cost figures for each policy. These figures were assembled in frequency distributions from which the 5th and 95th percentile values were obtained. The spread between these percentiles is a measure of sensitivity of the model output to uncertainty in the input parameters.

Figure 6.2 shows the results of the analysis. On the vertical axis the annual costs are plotted and on the horizontal axis the actual sediment loads. The 5th and 95th percentile costs are plotted for sediment load intervals of 10 tons/annum. It can be seen that there is considerable overlap between the policies, especially at severe sediment restrictions. This indicates that there is less difference in actual cost effectiveness between the management policies than would follow from the deterministic analysis. This might be different for larger river basins with larger ranges of total costs. The increased spread for lower permissible erosion rates is expected. Where the sediment load is increasingly limited, there are fewer choices of management practices that satisfy the limit, especially in the case of severe storms. As the sediment load becomes more limited eventually only two management practices may be employed. These are leaving the land covered, and therefore generating no revenue, or using a management practice with a high cost to maintain a low sediment load.

The results in Figure 6.2 show that the three policies may well lead to the same total costs given the uncertainty in the input parameter values. Compared to the Least Cost policy, the Erosion Standard policy and the Erosion Tax policy have a higher cost values at the 5th and the 95th percentile confidence limits. Moreover, the range of the total cost between these two limits is wide throughout the range of sediment standards, except at a sediment limitation less than 40 tons/annum. This is expected and can be explained as follows:

1) Under the Erosion Standard policy the limitation of erosion is applied for each LMU and therefore a more limited set of management options is available. There is no opportunity for combining LMUs and composing some centralized management strategy. Each LMU must meet the erosion limitation regardless of cost.

2) Under the Erosion Tax policy, an additional cost has to be paid for any erosion load greater than the allowable level. This additional cost could be the cost of reducing erosion by applying a better management practice, the cost of delivering any erosion load greater than the allowable level, or the cost of leaving the land as COVER.

Figure 6.3 shows the cummulative distribution functions (CDF) of the total cost for all three management policies at a total sediment load of 262 tons/annum. The CDF for a sediment limit of 48 tons/annum is shown in Figure 6.4. A steep CDF such as that for the Least Cost policy shown in Figure 6.3 indicates that there is little variation in the total cost due to the uncertainty in the input parameters, while a CDF such as that for all three policies shown in Figure 6.4 indicates a large influence of the uncertainty in the input parameters in the model outcome. These results show that, as the sediment load is restricted, the uncertainty in the input parameters has a greater influences on the model outcome.

The overlapping of the costs of these policies can also be seen in the CDFs in Figure 6.3 and Figure 6.4. These figures illustrate that the total cost for a given sediment limit using these three policies may lead to the same value. Moreover, the results show that with the more stringent sediment limitation, the difference between the 5th and the 95th percentile confidence limits for the three policies becomes small.

In summary it can be stated that the Least Cost policy has the most narrow confidence band, especially for large total sediment. This means that Least Cost policy is the most robust management policy. This is to be expected since the Least Cost policy is a centralized decision and therefore more choices of management practices are available. Conversely, the Erosion Standard policy has the widest confidence band because each farm has a limitation on its allowable erosion rate. There is no opportunity for combining farm practices as in a centralized decision. Each farm has to meet a limit on the amount of erosion allowed. Therefore, the Erosion Standard policy is the least robust management policy.

The crossing of the lines relating cost to sediment load in Figure 6.2 for different policies, and the overlapping of the costs of these policies in Figure 6.3 and 6.4, represents important information to the decision maker regarding the merits of these policies. It is commonly assumed that the cost associated with the Erosion Tax policy is always lower than for the Erosion Standard policy, and that the cost of the Least Cost policy is always the lowest. It is an important conclusion of this study that this may not always be so in cases where parameter values are uncertain. As noted for the deterministic case (Section 6.1), the maximum total RRR associated with meeting the sediment criteria for all three policies is only about $ 2,000.00/annum. Using the same sediment criteria, but considering uncertainty in the input parameters would lead to a maximum total RRR of $ 27,000.00/annum for the three policies, which is about 80% of the total revenue. These figures show that the cost of erosion control may be greatly under estimated when management practices are based on a deterministic solution. For larger river basins with larger ranges of total costs the conclusion might be different.

6.2.2 The Modified Generalized Sensitivity Analysis

The important parameters to be used in the model were identified using the Modified Generalized Sensitivity Analysis. The results are discussed in this section. As described in Chapter 5, a sensitivity index is used to measure the importance of the different input parameters to the model output. In this application, a sensitivity index greater than 1.0 indicates that the parameter is important to the model output at the 90% confidence level. Sensitivity indices are determined for each input parameter for each scenario. For the separation of the parameter values corresponding to the Behaviour and the Non-Behaviour categories two classification bases are used as explained in Section 5.2.4., the Watershed based classification and the Farm based classification. For the Watershed based classification, the Least Cost policy and the Erosion Tax policy are analyzed. For the Farm based classification, the Erosion Standard policy and the Erosion Tax policy are analyzed. The results are presented in Tables 6.9 to 6.17 and are discussed here.

6.2.2.1 The Watershed Based Classification Analysis

Tables 6.9 to 6.11 present the sensitivity indices for the 70 parameters for the Watershed based classification scheme and the Least Cost policy for a) an unrestricted sediment load, b) a sediment load limitation of 262 tons/annum, and c) a sediment load limitation of 48 tons/annum, respectively. The first two columns in the tables list the Transects and LMUs in the watershed (see also Table 5.1 for slope and soil formation). The remaining columns list the sensitivity indices. It may be noted that LMUs with a land slope of 13% or higher require COVER. They are therefore not considered further in the analysis. Table 6.9 shows that for an unrestricted sediment load, most of the sensitivity indices for parameters R, PR_c, PR_s, and PR_w are greater than one. This indicates that these parameters are important in terms of their influence on the model output at the 90% confidence level. The sensitivity indices for yield are mostly less than one. Only four out of sixty five yield parameters have a sensitivity index greater than one, the Y_c for LMUs with Soil Formation Orion 415A1 ($LMU_{2\,1}$, $LMU_{5\,2}$, and so on) and $LMU_{12\,2}$ with Soil Formation Cowden-Piasa 993A1/Herrick-Piasa 995A1; Y_s for $LMU_{11\,2}$ with Soil Formation Darmstadt 620C3; and Y_w for $LMU_{13\,3}$ with Soil Formation Huey 120A1/Herrick-Piasa 995A1.

As the total sediment load is restricted to 262 tons/annum and 48 tons/annum, some changes in the sensitivity indices occur. Parameters R, PR_c, PR_s, and PR_w, however, remain important. The sensitivity index for parameter R increases as sediment load is more restricted. For the prices and the yield parameters, no specific trend can be derived. Some of the sensitivity indices for prices and yield parameters increase and some decrease as total sediment load is more restricted. The number of significant yield parameters, however, does increase from four for the unrestricted sediment load to five for a sediment load limit of 262 tons/annum and to seven for a sediment load limit of 48 tons/annum. It is noted that the yield parameters that are important for an unrestricted sediment load remain important for the two limitations of sediment load. This shows that these parameters are consistently important. Although there is no strong indication that slope influences the significance of the input parameters (i.e., an increase in slope does not show an increase or decrease in the sensitivity index value), a general trend can be noted. The results show that for a slope smaller than or equal to 6%, some of the Y_c, Y_s, or Y_w parameters are important. However, for slopes greater than 6%, none of the yield parameter show any significance. The reason is that for a slope of less than or equal to 6%, combinations of CS or CSWDCS and NT and VT or CT and CN are predominantly shown as management practices in the Behaviour category. Other combinations of management practices in the Behaviour category are CCSWMMMM and CT and VT or CT and CN. This indicates that, to some degree, crops are still profitable while the erosion can be overcome by using NT as a tillage system or by using CN as a mechanical erosion control practice. For a slope gradient of greater than 6%, COVER is a common solution in the Behaviour category, although CCSWMMMM also occurs with NT as the tillage system and CN as the mechanical erosion control practice. This requirement, or the alternative option of leaving the land with cover, indicates that erosion is a significant issue. Therefore, for these fields, R is the most important parameter.

Tables 6.12 and 6.13 present the sensitivity indices for the Erosion Tax policy for a tax of \$2.00/ton and a tax of \$11.00/ton, respectively. For a tax of \$2.00/ton, the sensitivity indices for parameters R, PR_c , PR_s , and PR_w are greater than one. Eight out of the sixty five yield parameters are important parameters. As the tax increases to \$11.00/ton, the number of the important parameters for yield decreases from eight to three parameters. These yield parameters are Y_c for $\mathrm{LMU}_{11\,1}$ with Soil Formation Lawson 451A1 and $\mathrm{LMU}_{12\,2}$ with Soil Formation Darmstadt 620C3, and Y_w for LMU $_{15\,1}$ with Soil Formation Sable 68A1/Herrick Piasa 995A1. The sensitivity index for the rainfall erosivity parameter R increases and those for the price parameter PR_c, PR_s , and PR_w decrease as the tax increases. Some of the parameters P_w become insignificant for a tax of \$11.00/ton. The sensitivity index for parameter R is the largest for both levels. This shows that R is the most important parameter under the Erosion Tax policy. This can be explained as follows. Based on the USLE, erosion is directly affected by R. The larger the R, the larger the amount of soil lost. Since each ton of soil lost is taxed, the larger the erosion, the larger the cost. Parameter R is therefore important for both erosion and cost in the classification algorithm.

6.2.2.2 The Farm Based Classification Analysis

Tables 6.14 and 6.15 present the sensitivity indices for the Farm based classification and the Erosion Standard policy for erosion standards of 3 tons/acre and 1 ton/acre, respectively. The sensitivity indices are analyzed for each LMU. It was found that the sensitivity indices are the same for the same soil formation. The reason is that the input parameter R and the crop prices are the same for each LMU, while the yield parameters depend on the soil formation. Since each LMU is required to meet the erosion criteria, the important parameters in LMUs with the same soil formation are the same. It may be noted that LMUs with a slope of 13% or higher require COVER. They are therefore not considered further in the analysis. Table 6.14 shows that for LMUs with a slope smaller than or equal to 7.5%, sensitivity indices for parameters R, PR_c, PR_s, PR_w, Y_c, Y_s, and Y_w are greater than one, except PR_w and Y_w for $LMU_{11\,1}$. This indicates the significance of these parameters for the model outcome. About 50% of the sensitivity indices for parameter Y_d are also greater than one. This means that almost all the yield parameters except Y_m are important for these LMUs.

For an erosion standard of 1 ton/acre, the results in Table 6.15 show that for LMUs with a slope gradient greater than 4%, only R is important. For LMUs with slope gradient of 4% or less, the parameters R, PR_c, Y_c, Y_s, and Y_w that are important under an erosion standard of 3 tons/acre remain important under an erosion standard of 1 ton/acre. In general, the sensitivity indices for price parameters decrease and the sensitivity indices for yield parameters increase with more restricted erosion. This shows that when the erosion is more restricted, the yield parameters become more and the price parameters less important. The yield parameters affect the revenue and yield is important for the erosion reduction by crop residue.

The sensitivity indices for the Erosion Tax policy are presented in Tables 6.16 and 6.17 for a tax of \$2.00/ton and a tax of \$11.00/ton, respectively. The sensitivity indices for a tax of \$2.00/ton are similar to the sensitivity indices for an erosion standard of 3 tons/acre under the Erosion Standard policy, except for LMUs with a slope gradient of 6% and LMUs with a slope gradient of 6.3%. For $LMU_{11\,2}$, $LMU_{13\,1}$, $LMU_{14\,1}$, $LMU_{14\,2}$, and $LMU_{16\,3}$, with a slope gradient of 6%, parameters P_m and Y_m

are important for the Erosion Tax policy, but not important for the Erosion Standard policy. LMU_{121} with a slope gradient of 6.3%, requires COVER in most cases, and is therefore not profitable for the Erosion Tax policy. This LMU is still profitable for the Erosion Standard policy. The sensitivity indices for a tax of $11.00/ton soil loss are similar to the sensitivity indices for an erosion standard of 1 ton/acre, except for LMU_{83}. LMU_{83}, with a slope gradient of 7.5%, is still profitable for the Erosion Tax policy, but it is not profitable for the Erosion Standard policy. The limitation on soil loss forces changes from crop land to non-crop land for the Erosion Standard policy, while this land is still profitable for the Erosion Tax policy.

6.2.3 Results of the Regret and Robustness Analyses

The results of the Regret and Robustness Analyses for determining the robust management practices for the study based on the watershed as a whole and the individual farm conditions are presented in Tables 6.18 to 6.30 and in Tables A.1 to A.12 and discussed below.

6.2.3.1 Watershed Based Management Analysis

Table A.1 shows the results of the Regret and Robustness Analyses for the Watershed based analysis for the one hundred Monte Carlo realizations. Only the end results are presented here, the procedure is described in Section 4.3.1.1 and Section 5.2.5. The first column lists the input scenarios that were generated by Monte Carlo Simulation. One hundred scenarios were investigated. The second column lists the optimum sets of management practices *MD* for each input scenario. Each set consists of 37 subsets of management practices, i.e., one for each LMU. Each set is the optimum for the particular input scenario. That is, *MD1* is optimal for Input Scenario *1*, and *MD2* is optimal for Input scenario *2*, and so on. The third and fourth columns show the maximum regret and the expected regret with respect to the total revenue for each management set (*MD*). The next three columns show the maximum over-design marked with the (+) sign, the maximum under-design denoted by the (-) sign, and the expected regret with respect to the total sediment load for each *MD*. The last six columns show the results of the Robustness Analysis. Of these the first three columns show the frequencies of meeting the total revenue limits, which were taken as 85%, 90%, and 95% of the maximum revenue for the given input scenario. The remaining three columns show the frequencies of meeting the total sediment load limits, for which sediment loads of 200 tons/annum, 150 tons/annum, and 100 tons/annum were used.

Table A.1 shows that the minimum of the maximum revenue regrets for the 100 Monte Carlo results from *MD7* and is $6,039.00/annum. The next lowest value results from *MD69* and is $6,045.00. The minimum of the average or expected revenue regret value is $785.00. It results from *MD70*. The second lowest expected revenue regret value results from *MD7* and is $2046.00. One may conclude from this that the aim of minimizing either maximum or average regret with respect to revenue leads to management practices *MD7*, *MD69* or *MD70* as the best choices.

The smallest range between the over-design and under-design in terms of sediment regret is 205 tons/annum. This results from *MD19*. The second lowest range is 215 tons/annum which results from *MD70*. The minimum of the maximum under-design in terms of sediment regret results from *MD19* and is 0 ton/annum. The second lowest value is 24 tons/annum which results from *MD70*.

The least average or expected sediment regret results from *MD75* and is 4.80 tons/annum. The second lowest value is 5.70 tons/annum. It results from *MD89*. The conclusion is that to minimize regret in terms of total sediment load, *MD19*, *MD70*, *MD75*, or *MD89* can be selected.

It is evident that Regret Analysis leads to different "best" management practices dependent on how regret is expressed and on whether it is expressed in terms of revenue or sediment. The analysis, however, identifies a limited number of management options from which a good choice can be made. These are *MD7*, *MD19*, and *MD70*.

Turning now to the results of the Robustness Analysis, the highest frequency of meeting the three revenue limits, 85%, 90%, and 95% of the maximum revenue, is obtained by *MD70* with a frequencies of 95%, 89%, and 74%, respectively. This is followed by *MD7*, with frequencies of 75%, 53%, 27%, respectively. In terms of meeting the sediment limits, *MD19* yield the "best" sets of management practices, with frequencies of 100%, 97%, and 80%, for load limits of 200 tons/annum, 150 tons/annum, and 100 tons/annum, respectively. The second and the third highest frequencies can be obtained with *MD80* and *MD70* with frequencies of 97%, 94%, 59%, and 97%, 93%, and 60%, respectively. A comparison between the three sets of management practices shows possible trade-offs between sediment load and revenue when the watershed as a whole is considered.

Combining the results of the Regret Analysis and the Robustness Analysis requires a trade-off between *MD7*, *MD19* and *MD70*. If the primary interest is revenue, then *MD70 or MD7* can selected. *MD70* gives the least expected revenue regret in the regret analysis, and the highest frequency of meeting the revenue limits in the robustness analysis. *MD7* gives the lowest maximum revenue regret and the second lowest expected revenue regret in the regret analysis. It has the second highest frequency of meeting the revenue limits in the robustness analysis. If the interest is in both revenue and sediment, *MD70* is the best selection since it results also in the second lowest sediment regret. If the primary interest is in meeting the sediment restriction, then *MD19* is the best selection since it results in the smallest range between over and under-design in terms of sediment regret in the regret analysis, and the highest frequency of meeting the sediment limits in the robustness analysis. A summary of the regret and robustness analyses for these three sets of management practices is hown in Table 6.18. Table 6.19 shows the three sets of management practices.

CCSWMMMM is used more in *MD19* than in *MD7* or *MD70*. CCSWMMMM is a crop rotation that reduces erosion by the use of meadow. This crop rotation however is not as profitable as CS or CSWDCS. This may be the reason why *MD19* is better in terms of sediment and not in terms of revenue when compared to the other two sets of management practices. All three sets of management practices use either NT as tillage system or CN as mechanical erosion control in the LMUs adjacent to the stream. This may be why these three sets of management practices are robust in terms of sediment. Combinations of CS or CSWDCS for crop rotation, CV or NT for tillage system, and VT or CN for mechanical erosion give relatively high revenues compared to other sets of management practices such as the CSWM crop rotation and the FP tillage system.

6.2.3.2 Farm Based Management Analysis

Tables A.2 to A.12 and Tables 6.20 t0 6.30 present the results of the Regret and Robustness Analyses for the Farm based analysis. Only the end results are presented, the procedure is as described in Section 4.3.1.2 and Section 5.2.5. Tables A.2 to A.12 have the same format, Table A.2 will be used as an example in the following discussion. The first column lists the input scenarios that were generated by Monte Carlo Simulation. One hundred scenarios were investigated. The second column lists the optimum management practices *M* for each input scenario. The rest of the columns are similar to those in Table A.1.

It may be noted that for the Farm based analysis the same management practice may be optimal for more than one input scenario. For example, the results in Table A.2 shows that the optimal management practice for input scenarios *1*, *6*, *10*, *11*, *13*, and *14* are the same. This shows that for many input scenarios this particular management practice meets the erosion criteria while maximizing farm revenue. Of the 30 management practices that were analyzed for each LMU, only nine show up as optimum management practices for all LMUs in 100 Monte Carlo realizations. A summary of these management practices is shown in Table 6.20.

The best management practices in terms of regret and robustness will be discussed below. For this purpose the LMUs are divided into eleven groups of similar cases. The first group consists of $LMU_{1\,2}$, $LMU_{3\,2}$, $LMU_{9\,3}$, and $LMU_{16\,2}$. All these have a slope of 4%. They also have the same soil formation, namely Marine 517B1, which means that the results of the Regret and Robustness Analyses are the same for these LMUs. They are shown on Tables A.2 and 6.20. The lowest maximum revenue regret and expected revenue regret result from *M7.* The values are \$77.00/acre/annum and \$7.10/acre/annum, respectively. The second lowest values are \$82.00/acre/annum and \$29.10/acre/annum, resulting from *M1.*

In terms of erosion regret, *M7* and *M9* give the lowest range between the over-design and under-design for the first group of LMUs. *M7* also results in the lowest maximum under-design in terms of erosion regret, while *M9* results in the second lowest value. These two management practices also produce the lowest average or expected erosion regret, *M9* being the lowest and *M7* being the third lowest.

The results of the Robustness Analysis show that the highest frequency of meeting the three revenue limits, 85%, 90%, and 95% of the maximum revenue, is obtained by *M7* with frequencies of 82%, 76%, and 71%, respectively. This is followed by *M9*, with frequencies of 36%, 31%, 24%, respectively. In terms of meeting the erosion limits, *M7* shows up as the "best" management practice, with frequencies of 100%, 99%, and 92% for erosion limits of 2.00 tons/acre/annum, 1.50 tons/acre/annum, and 1.00 tons/acre/annum, respectively. The second and the third highest frequencies are obtained with *M9* with frequencies of 98%, 95%, 69%.

Combining the results of the Regret Analysis and the Robustness Analysis for this group of LMUs requires a trade-off between *M7* and *M9*. These two consistently result in the lowest regret with respect to revenue and erosion and the highest frequency of achievement in terms of meeting the revenue and erosion limits. Management practice *M7* consists of a combination of CSWDCS, NT, and CN, while *M9* consists of CCSWMMMM, NT, and VT. Both management practices utilize NT as tillage practices. As described in 5.1.1.1.2, NT is considered to be the most effective technique for reducing soil erosion which is important since these LMUs have slopes of 4%. The selection of CN for *M7* is in agreement with the recommendation given in Illinois Agronomy Handbook (1982). The CN alternative is mostly effective for slopes ranging from three to eight percent. This result is also in agreement with the results of the Modified Sensitivity Analysis, which show the importance of the yield and price parameters for corn, soybeans, and wheat. The *R* parameter, which is related to erosion becomes less important with the use of NT as tillage practice, CN as mechanical erosion control in *M7*, and Meadow in *M9*.

The second LMU group consists of LMU_{21}, LMU_{52}, LMU_{62}, LMU_{71}, LMU_{81}, and LMU_{91}. These LMUs have a slope of 1% and have the same soil formation, namely Orion 415A1. The results of the Regret and Robustness Analyses for these LMUs are presented in Tables A.3 and 6.21. Of the 30 management practices that were analyzed for these LMUs, only 10 show up as optimum management practices for the 100 Monte Carlo realizations. The lowest maximum revenue regret results from *M7* with a value of \$68.00/acre/annum. The second lowest results from *M9* with values of \$71.00/acre/annum. *M7* also results in the lowest expected erosion regret. *M9* also results in the lowest expected revenue regret, the lowest range between over-design and under-design erosion regret, and the lowest maximum under-design erosion regret. The conclusion is that to minimize regret in terms of revenue and erosion, *M9* and *M7* can be selected.

The results of the Robustness Analysis show that the highest frequency of meeting the three revenue limits, 85%, 90%, and 95% of the maximum revenue, is obtained by *M9* with frequencies of 93%, 84%, and 74%, respectively. This is followed by *M7*, with frequencies of 88%, 76%, 22%, respectively. In terms of meeting the erosion criteria, *M7*, *M8*, *M9*, and *M10* result in the highest frequency of compliance, with frequencies of 100%, 100%, and 100%, respectively for erosion limits of 2.00 tons/acre/annum, 1.50 tons/acre/annum, and 1.00 ton/acre/annum, respectively. These four management practices utilize NT as tillage practices.

Combining the results of the Regret and Robustness Analyses shows that *M9* and *M7* can be selected as robust management practices for this group. Management practice *M9* consists of a combination of CSWDCS, NT, and CN. *M7* consists of CSWDCS, NT, and VT. *M7* which uses CN as mechanical erosion control results in a lower under-design erosion regret and a higher over-design erosion regret, but a higher maximum revenue regret. Conversely, *M9*, results in a lower maximum revenue regret and higher under-design erosion regret. The difference between these two management practices is not significant here, especially with respect to the erosion rate. However, the difference in the frequency of meeting the revenue criteria is quite significant, especially for the 95% of the maximum revenue limit. This can be explained as follows. Since the LMUs in this group have a slope of only 1%, i.e., reducing the flow velocity by aligning furrows perpendicular to the slope may not be necessary. However, CN may be useful in terms of maintaining the soil moisture. For both management practices, CSWDCS is used as crop rotation, since this is the most profitable combination of crops. Again, the results are in agreement with the results of the Modified Generalized Sensitivity Analysis, where the yields and prices of corn, soybeans, and wheat are important. Although NT is not necessary for fields with small slope steepness (Illinois Agronomy Handbook, 1982), the results show that in the presence of uncertainty in the input parameters, CT will result in a high revenue regret and erosion regret. Here, *M1* consisting of CSWDCS, CT, and VT, results in a maximum revenue regret of $131.00/acre/annum, and a range between the over-design and under-design erosion regret of 3.8 tons/acre/annum. The maximum under-design of 3.48 tons/acre/annum shows that CT results in a high erosion for high intensity storms. Moreover, CT may be more profitable in case of low or moderate storms, but the high value of the maximum revenue regret shows that large fluctuations may occur in the farm revenue. The reason is that CT results in high erosion rate during high intensity storms, which decrease yields, i.e., decrease revenue. These results show the importance of including uncertainty in the input parameters in selecting the appropriate management practices, even for mild slopes.

Tables A.4 and 6.22 show the results for the third LMU group which consists of $LMU_{4\,1}$, $LMU_{5\,1}$, and $LMU_{6\,1}$. These LMUs have a slope of 1.4%. For these LMUs, 10 out of 30 management practices show up as optimum management practices. The lowest maximum revenue regret results from *M10* with a value of $70.00/acre/annum. This is followed by *M7* with a value of $75.00/acre/annum. These two management practices also result in the first and second lowest expected revenue regret, i.e., $9.40/acre/annum and $16.80/acre/annum, respectively. In terms of expected erosion regret, *M6* results in the lowest value. The second lowest results from *M7* and *M9*. *M10* results in the lowest range between over-design and under-design erosion regret, followed by *M9* and *M7*. The lowest maximum under-design erosion regret results from *M10*.

Turning now to the results of the Robustness Analysis, the highest frequency of meeting the three revenue limits, 85%, 90%, and 95% of the maximum revenue, is obtained by *M10* with frequencies of 86%, 78%, and 63%, respectively. This is followed by *M7*, with frequencies of 80%, 66%, 22%, respectively. In terms of meeting the erosion criteria, *M6*, *M7*, *M9*, and *M10* result in the highest frequency, with frequencies of 100%, 100%, and 100%, respectively for erosion rates of 2.00 tons/acre/annum, 1.50 tons/acre/annum, and 1.00 tons/acre/annum, respectively.

Combining the results of the Regret Analysis and Robustness Analysis shows that *M10* performs better than the other management practices. This is followed by *M7*. Therefore, *M10* and *M7* can be selected as the robust management practice for LMU$_{4\,1}$, LMU$_{5\,1}$, and LMU$_{6\,1}$. *M10* consists of a combination of CSWDCS, NT, and CN. *M7* consists of CSWDCS, NT, and VT. These LMUs have a slope steepness of 1.4%. These robust management practices for these are similar to those described earlier for LMUs with slope steepness of 1%.

Next the results for LMU$_{8\,3}$ will be discussed. They are presented in Tables A.5 and 6.23. Only 5 of the 30 management practices show up as optimum management practices. This LMU has a slope of 7.5%, which is a relatively steep slope. A steeper slope will result in a larger erosion rate. Therefore, the choice of management practices that meet the erosion criteria is more limited. The lowest maximum revenue regret results from *M5* with a value of $61.00/acre/annum. The second lowest results from *M1* with a value of $70.00/acre/annum. *M5* also results in the lowest expected revenue regret and the lowest expected erosion regret, $14.20/acre/annum and 0.07 tons/acre/annum, respectively.

In terms of the range of the over and under-design for erosion control, *M4* results in the lowest value. This is followed by *M5*. Although *M1* has the second lowest maximum revenue regret, it results in a high range of over and under-design, i.e., 9.9 tons/acre/annum.

For LMU$_{8\,3}$ the results of the Robustness Analysis show that the highest frequency of meeting the three revenue criteria, 85%, 90%, and 95% of the maximum revenue, is obtained by *M5* with frequencies of 31%, 31%, and 31%, respectively. This is followed by *M1*, with frequencies of 26%, 23%, 21%, respectively. In terms of meeting the erosion criteria, *M4* has the "best" set of management practices, with frequencies of 100%, 100%, and 100% for the three erosion rates. This is followed by *M5* and *M1* with frequencies of 93%, 72%, 30% and 40%, 17%, and 7%, respectively.

Combining the results of the Regret Analysis and the Robustness Analysis shows that *M5* can be selected. *M4* could also be selected if the primary concern is with the erosion criteria, but *M4* results in the highest maximum revenue regret since *M4* consists of COVER. It is therefore expected that *M4* results in a 100% frequency of meeting the erosion criteria considered. *M5* consists of a combination of CCSWMMMM, NT, and CN. These results are representative of a solution for a field with steep slope, COVER results in the lowest erosion rate, but entails a total loss of revenue. The combination of CCSWMMMM, NT, and CN as the potential crop for this LMU has a range of 4.89 tons/acre/annum between the over and under-design erosion regret. These results are in agreement with the results of the Modified Generalized Sensitivity Analysis, where the yields and prices of corn, soybeans, and wheat strongly influence the model results, while the yield of double-crop-soybeans is not important.

The next LMU to be discussed is LMU $_{11\,1}$. Tables A.6 and 6.24 show the results for this LMU. Of the 30 management alternatives that were analyzed, only 9 show up as optimum management practices for the one hundred Monte Carlo realizations. The lowest maximum revenue regret results from *M8*. The second lowest results from *M7*. Their values are \$75.00/acre/annum and \$80.00/acre/annum, respectively. *M7* and *M8* also result in the first and second lowest expected revenue regret, i.e., \$12.70/acre/annum and \$20.50/acre/annum, respectively.

In terms of expected erosion regret, *M5* results in the lowest value, while *M6* produces the second lowest value. *M9* gives the lowest range between over and under-design erosion regret. This is followed by *M8* and *M7*. The lowest maximum under-design erosion regret results from *M8*.

For LMU $_{11\,1}$ the results of the Robustness Analysis show that the highest frequency of meeting the three revenue criteria, 85%, 90%, and 95% of the maximum revenue, is obtained by *M7* with frequencies of 84%, 73%, and 56%, respectively. This is followed by *M8*, with frequencies of 82%, 60%, 43%, respectively. In terms of meeting the three erosion criteria, *M5*, *M6*, *M7*, *M8*, and *M9* result in the highest frequency, with frequencies of 100%, 100%, and 100%, respectively.

Combining the results of Regret and Robustness Analysis requires a trade-off between *M7* and *M8* for LMU $_{11\,1}$. *M7* consists of a combination of CS, NT, and CN, while *M8* consists of CSWDCS, NT, and CN. This LMU has a slope of 2%. Both management practices required NT and CN in meeting the erosion criteria. The difference in the crop rotation is expressed in the revenue regret.

Compared to CSWDCS, CS is more profitable and the frequency of meeting the revenue criteria is also higher.

The next group to be discussed consists of LMU$_{11\,2}$, LMU$_{13\,1}$, LMU$_{14\,1}$, LMU$_{14\,2}$, and LMU$_{16\,3}$. Tables A.7 and 6.25 show the results for these LMUs. Nine of the 30 management practices that were analyzed show up as optimum management practices. The lowest maximum revenue regret results from *M9*. The second lowest results from *M8*. Their values are $43.00/acre/annum and $44.00/acre/annum, respectively. *M6* results in the lowest expected revenue regret, while *M2* results in the second lowest expected revenue regret.

The lowest range between over and under-design erosion regret, and the minimum of the maximum under-design erosion regret is obtained from *M6*, with a value of 2.81 tons/acre/annum. This is followed by *M4* with a value of 5.24 tons/acre/annum.

The results of the Robustness Analysis for this LMU group show that the highest frequency of meeting the three revenue criteria is obtained by *M8* with frequencies of 15%, 12%, and 12%, respectively. In terms of meeting the three erosion criteria, *M7* results in the highest frequencies, with frequencies of 100%, 100%, and 100%, respectively. This is followed by *M4* with frequencies of 91%, 68%, and 28%, respectively.

Combining the results of the Regret Analysis and the Robustness Analysis requires trade-offs between *M4* and *M6*. Both management practices are robust with respect to erosion criteria, but not with respect to revenue criteria. If the primary interest is in the revenue criteria, *M8* can be selected. Although the frequency of meeting the three revenue criteria is small, *M8* results in a high under-design erosion regret, i.e., 10.13 tons/acre/annum. *M4* consists of CCSWMMMM, NT, and CN, *M6* consists of COVER, and *M8* consists of CCSWMMMM, CT, and VT. It is noted that these LMUs have a slope steepness of 6%. For these LMUs, CS and CSWDCS are not selected since they result in a high erosion rate. Similar to LMU$_{8\,3}$, these LMUs require meadow, NT, and CN to meet the erosion criteria.

The results for LMU$_{12\,1}$ is shown in Tables A.8 and 6.26. LMU$_{12\,1}$ has a slope of 6.3% which is close to the slope of the previous group. The use of CCSWMMMM, NT, and CN will result in a maximum revenue regret of $50.00/acre/annum and a maximum revenue regret of $14.30/acre/annum. The maximum range of over and under-design erosion regret is 5.02 tons/acre/annum and the maximum under-design is 2.75 tons/acre/annum. The frequencies of meeting the three revenue criteria are all 24%, while the frequencies of meeting the erosion criteria are 93%, 69%, and 31%. When COVER is applied to this LMU, the frequency of meeting the erosion criteria is 100%, while the frequency of meeting the revenue criteria is the least.

Next to be discussed are the results for $\text{LMU}_{12\,2}$. They are presented in Tables A.9 and 6.27. For this LMU, 10 of the 30 management practices that were analyzed show up as optimum management practices for the 100 Monte Carlo realizations. Based on the results of Regret Analysis, *M7* and *M10* can be selected as the robust management practices in terms of regret with respect to revenue. *M5*, *M8*, and *M9* can be selected as the robust management practices in terms of regret with respect to erosion. The results of the Robustness Analysis show that *M7* and *M10* can be selected with respect to revenue and erosion criteria.

Combining both Regret and Robustness Analysis requires trade-offs between *M7* and *M10* for $\text{LMU}_{12\,2}$. *M7* consists of CSWDCS, NT, and VT and *M10* consists of CSWDCS, NT, and CN. These two management practices are similar to previous results for fields with slope steepness of 1%.

The next group to be discussed includes $\text{LMU}_{13\,2}$, $\text{LMU}_{14\,3}$, and $\text{LMU}_{15\,2}$. The results are presented in Tables A.10 and 6.28. For these LMUs, only 8 management practices are optimum management practices for the 100 Monte Carlo realizations. Two of these management practices perform best. They are *M5* and *M6*. *M5*, which consists of CSWDCS, NT, and CN results in the lowest value for all the regret measures, except for the expected erosion regret. The maximum revenue regret is $64.00/acre/annum. The expected revenue regret is $8.60/acre/annum. The maximum range between the over and under-design erosion rate is 2.38 tons/acre/annum, and the expected erosion regret is 0.22 tons/acre/annum. For the Robustness Analysis, *M5* also results in the highest frequency of meeting both criteria, the revenue criteria and the erosion criteria. *M6*, which consists of CCSWMMMM, CT, and CN, results in the second lowest regret measures and the second highest robustness measures. The slope of these LMUs is 2.5%. Based on the deterministic case, CSWDCS, CT, and CN are selected as the management practices for these LMUs. If CSWDCS, CT, and CN are applied, the results of the Regret and Robustness Analysis is represented by *M1*, the maximum revenue regret and the expected revenue regret are \$90.00/acre/annum and \$31.2/acre/annum, respectively. The range of the erosion regret is 5.80 tons/acre/annum with a maximum under-design of 4.17 tons/acre/annum. In terms of the Robustness Analysis, the frequencies of meeting the three revenue criteria are 6% and lower. The frequencies of meeting the three erosion rate criteria are 44% and lower. The NT tillage system or crop rotation with meadow is required to obtain a higher frequency of meeting both criteria.

The last group of LMUs to be discussed consists of $\text{LMU}_{13\,3}$ and $\text{LMU}_{15\,1}$. Tables A.11 and A.12, 6.29 and 6.30 show the results of the Regret and Robustness Analyses for this group. These LMUs, with a slope of 1%, have several alternatives of robust management practices in terms of regret and robustness measures with respect to erosion. These management practices are *M4*, *M7*, *M8*, *M9*, *M10* for $\text{LMU}_{13\,3}$, and *M3*, *M6*, *M7*, *M8*, *M9* for $\text{LMU}_{15\,1}$. However, the difference in regret and robustness measures with respect to revenue is quite significant. The revenue regrets could differ by a factor four (*M7* and *M9*). Based on both Regret and Robustness Analyses with respect to revenue and erosion, *M7* and *M10* result as the first and second robust management practice for $\text{LMU}_{13\,3}$. *M7* and *M6* result as the first and second robust management practice for $\text{LMU}_{15\,1}$. As shown in Tables A.11 and A.12, the first choice for both LMUs is CSWDCS, NT, and VT. The second choice for $\text{LMU}_{13\,3}$ is CCSWMMMM, NT, and VT, while for $\text{LMU}_{15\,1}$ it is CS, NT, and VT. Again, it is shown that NT is required as the tillage practice, while CT is selected under the deterministic case. The difference in the values of regret and robustness measures are not large. For $\text{LMU}_{13\,3}$, the maximum revenue regret using CSWDCS, CT, and VT may be \$168.00/acre/annum, and an expected revenue regret of \$63.90/acre/annum, compared with values of \$48.00/acre/annum and \$8.30/acre/annum for CSWDCS, NT, and VT.

6.2.3.3 Summary

In summary, the results of the Regret and Robustness Analyses for the Watershed based analysis and the Farm based analysis show that robust management alternatives are somewhat different for the two bases of management. The significant difference is in the tillage practices. For the Watershed based analysis, CT is widely preferred, while for the Farm based analysis NT is preferred. This is not surprising since the Farm based analysis forces each farm to meet the erosion limits and NT is the most effective way of reducing soil erosion in crop land. For both analysis bases, CN is widely preferred as the mechanical control practice.

In most cases, desirable crop rotations depend on soil formations and slope. COVER is preferred for LMUs with a slope of 13% or higher. CSWDCS is the preferred crop rotation for LMUs with a slope less than 2%, while CS or CSWDCS can be used as crop rotations for LMUs with a slope of 2%. For land with a slope greater than 2% and up to 4%, CSWDCS or CCSWMMMM are preferred. CCSWMMMM or COVER is required for LMUs with a slope of 6% to 8%. An exception to this exists for one field, namely LMU_{83} which has a slope of 7.5%. In spite of its steep slope, this LMU is still profitable with the Watershed based analysis. Three acceptable crop rotations are available for LMU_{83}, CS, CSWDCS and CCSWMMMM. For Farm based analysis, this LMU may or may not be profitable. The rotation CCSWMMMM is the only crop rotation that can be used as an alternative to keeping the land in COVER. The reason for this is that this particular LMU is unique in two ways. First, this field has the soil formation Elco 119C3 which produces high yields. Moreover, the erodibility factor of this soil is similar to other soil formations having a 4% slope or less. Second, the field is the third field from the stream while the second field is growing COVER. Consequently, the sediment originating from this LMU is mostly deposited on the second field. It does not significantly affect the sediment entering the water-body, which is the criterion used in Watershed based analysis.

The results of the Regret and Robustness Analyses show that management practices based on deterministic input data may lead to large discrepancies between calculated and actual values for erosion rate, sediment load and revenue. This shows the importance of including uncertainty in the input parameters in determining appropriate management practices. The Regret and Robustness measures can be used to identify what management practices are robust in terms of erosion and revenue. This is important information for the decision maker.

6.2.4 Effect of the Location of an LMU on Sediment Load and Management Practice

The location of an LMU relative to a stream plays an important role in the sediment load which it can transmit to the stream. The LMUs adjacent to the stream are therefore quite important in the choice of robust management practices for the Watershed based management. An example of this is LMU_{83} the management of which is described in Section 6.2.3. The effect of the location of the LMUs on their sediment contribution was examined by comparing the contribution of several LMUs with the same land slope but located at different distances upslope from the stream. LMUs with slopes varying between 1% to 7.5% were analyzed for locations of up to eight fields upslope from the stream. It was found that the contribution of each field to the stream depends on the slope sequence between that field and the stream. A significant change in slope gradient, either from steep to mild or from mild to steep, substantially reduces the sediment contribution of the field compared to the case of a uniform slope between that field and the stream.

The reason for this is that in the long run the sediment transported across a field boundary cannot exceed the amount eroded uphill from that boundary nor the transport capacity of the downhill field. Assuming the same soil formation and the same field management, the amount of eroded material that reached the stream is governed by the smallest of the two slopes, the slope of the uphill and that of the downhill field. This means that the sediment load on the stream tends to be less for a sequence of fields with different slopes than for a sequence of fields that all have a slope equal to the average slope. The management, however, is not always the same in a sequence of fields leading to a stream. The conclusion, however, is the same.

When the slope changes in a downhill direction from mild to steep, sedimentation control depends on the management practices of the downhill field. In the uphill fields with a mild slope, CS or CSWDCS is indicated as crop rotation, since these are the most profitable crops in the study area. These two crop rotations, however, result in a fairly high erosion rate compared to other crop rotations for the same tillage system. The fields with a steep slope, on the other hand, require either a combination of CS or CSWDCS as crop rotation, with NT as tillage system, and CN as mechanical erosion control, or a combination of CCSWMMMM, CT, with VT as appropriate management practice. Both sets of management practices result in low erosion rate with proper management. It follows therefore that a change from a mild to a steep slope in a downhill direction decreases the sediment delivery to the stream compared to a uniform slope.

When the slope changes from steep to mild in a downhill direction, a decrease in transport capacity can be expected, compared with a uniform slope for all acceptable management practices that would be suitable for the lower land. One may conclude that the configuration of the slope in a downhill direction greatly influences the contribution of the field sequence to the total sediment in the stream. The closer these change in slope are to the stream bed, the greater the effect on the total sediment delivery.

Figure 6.1 Trade-off between Total Sediment and Total Cost for the Deterministic Input under the Three Management Policies

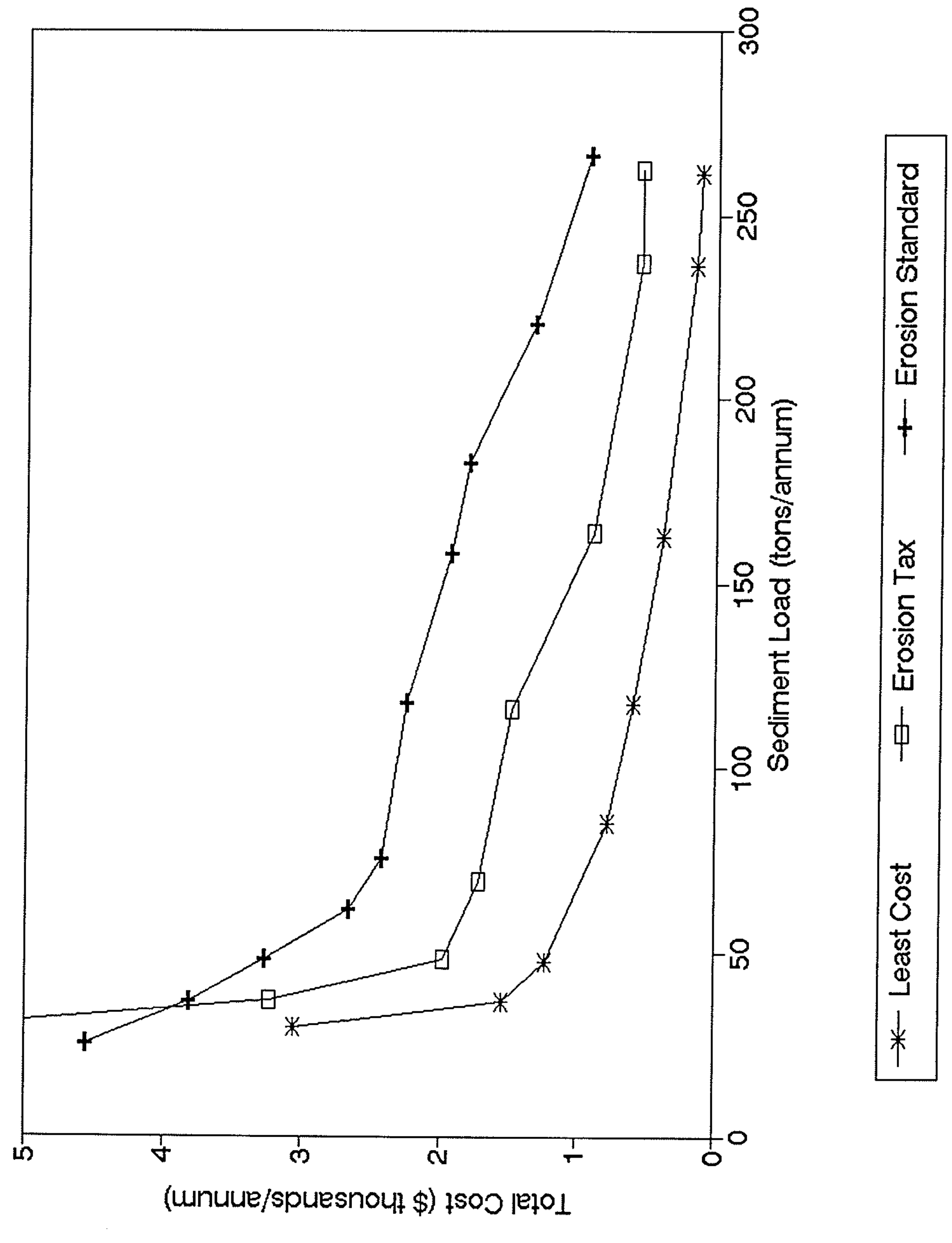


Figure 6.2 The 5th and 95th Percentile Confidence Limits of the Total Cost under Various Sediment Loads for the Three Management Policies

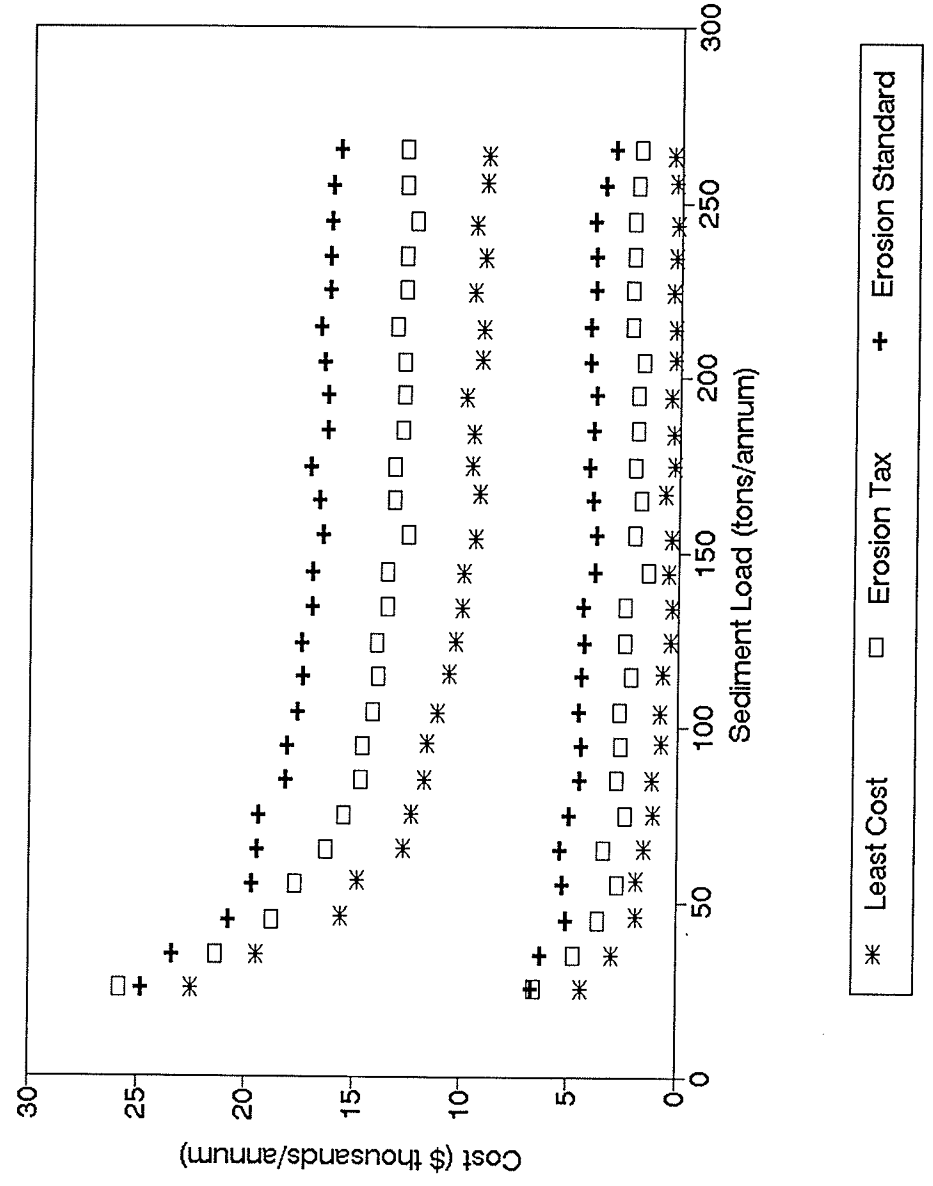
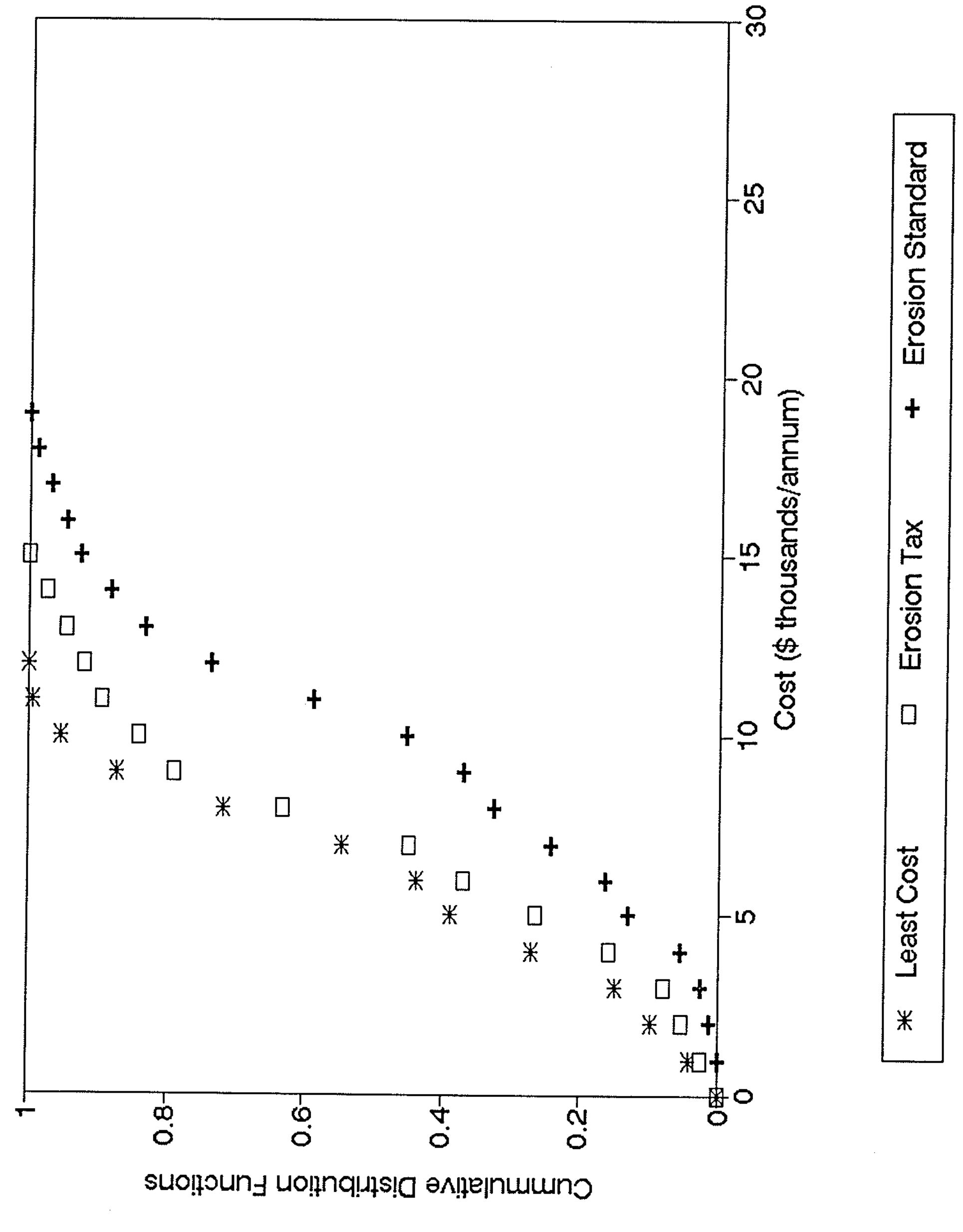


Figure 6.3 The CDFs of the Total Cost for a Total Sediment Load of 262 tons/annum under the Three Management Policies



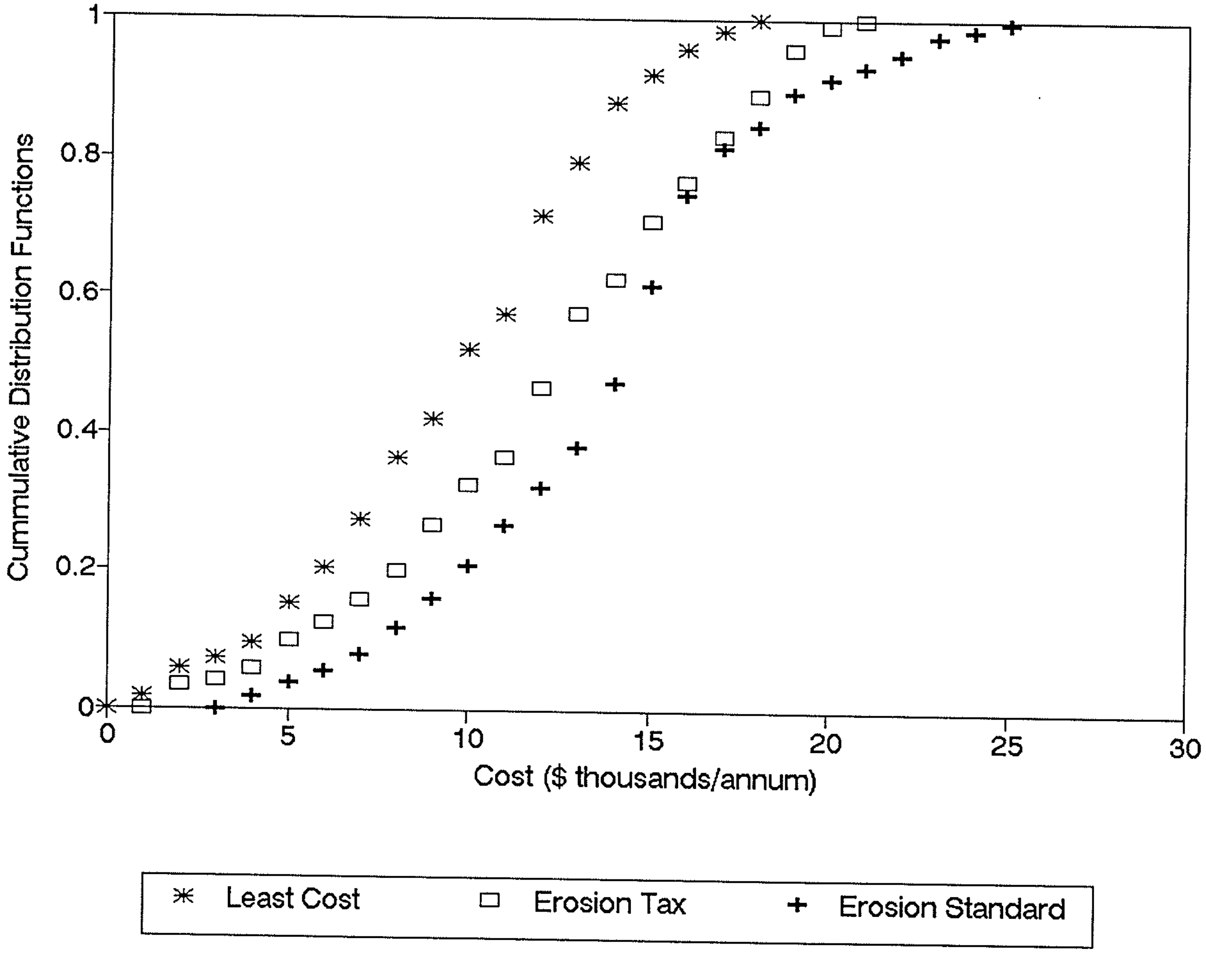


Figure 6.4 The CDFs of the Total Cost for a Total Sediment Load of 48 tons/annum under the Three Management Policies

Table 6.1 Management Practices Under the Least Cost Policy for an Unconstrained Sediment Load

Transect	LMU	SLOPE (%)	Crop Rotation	Tillage System	Mechanical Control
1	1	13.0	COVER		
	2	4.0	CSWDCS	CT	VT
2	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
3	1	13.0	COVER		
	2	4.0	CSWDCS	CT	VT
4	1	1.4	CSWDCS	CT	VT
	2	13.0	COVER		
5	1	1.4	CSWDCS	CT	VT
	2	1.0	CSWDCS	CT	VT
	3	23.0	COVER		
6	1	1.4	CSWDCS	CT	VT
	2	1.0	CSWDCS	CT	VT
	3	13.0	COVER		
7	1	1.0	CSWDCS	CT	VT
8	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
	3	7.5	CSWDCS	CT	VT
9	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
	3	4.0	CSWDCS	CT	VT
10	1	13.0	COVER		
11	1	2.0	CS	CT	VT
	2	6.0	CSWM	CT	VT
12	1	6.3	CSWM	CT	VT
	2	1.0	CSWDCS	CT	VT
13	1	6.0	CSWM	CT	VT
	2	2.5	CSWDCS	CT	VT
	3	1.0	CSWDCS	CT	VT
14	1	6.0	CSWM	CT	VT
	2	6.0	CSWM	CT	VT
	3	2.5	CSWDCS	CT	VT
15	1	1.0	CSWDCS	CT	VT
	2	2.5	CSWDCS	CT	VT
16	1	13.0	COVER		
	2	4.0	CSWDCS	CT	VT
	3	6.0	CSWM	CT	VT

Table 6.2 Management Practices Under the Least Cost Policy for a Sediment Load Limitation of 262 tons/annum

Transect	LMU	SLOPE (%)	Crop Rotation	Tillage System	Mechanical Control
1	1	13.0	COVER		
	2	4.0	CSWDCS	CT	VT
2	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
3	1	13.0	COVER		
	2	4.0	CSWDCS	CT	VT
4	1	1.4	CSWDCS	CT	VT
	2	13.0	COVER		
5	1	1.4	CSWDCS	CT	VT
	2	1.0	CSWDCS	CT	VT
	3	23.0	COVER		
6	1	1.4	CSWDCS	NT	VT
	2	1.0	CSWDCS	CT	VT
	3	13.0	COVER		
7	1	1.0	CSWDCS	CT	VT
8	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
	3	7.5	CSWDCS	CT	VT
9	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
	3	4.0	CSWDCS	CT	VT
10	1	13.0	COVER		
11	1	2.0	CS	CT	VT
	2	6.0	CSWM	CT	VT
12	1	6.3	COVER		
	2	1.0	CSWDCS	CT	VT
13	1	6.0	CSWM	CT	CN
	2	2.5	CSWDCS	CT	VT
	3	1.0	CSWDCS	CT	VT
14	1	6.0	CSWM	CT	CN
	2	6.0	CSWM	CT	VT
	3	2.5	CSWDCS	CT	VT
15	1	1.0	CSWDCS	CT	VT
	2	2.5	CSWDCS	CT	VT
16	1	13.0	COVER		
	2	4.0	CSWDCS	CT	VT
	3	6.0	CSWM	CT	VT

Table 6.3 Management Practices Under the Least Cost Policy for a Sediment Load Limitation of 48 tons/annum

Transect	LMU	SLOPE (%)	Crop Rotation	Tillage System	Mechanical Control
1	1	13.0	COVER		
	2	4.0	CSWDCS	CT	VT
2	1	1.0	CSWDCS	NT	VT
	2	13.0	COVER		
3	1	13.0	COVER		
	2	4.0	CSWDCS	CT	VT
4	1	1.4	CSWDCS	NT	VT
	2	13.0	COVER		
5	1	1.4	CSWDCS	NT	CN
	2	1.0	CSWDCS	CT	VT
	3	23.0	COVER		
6	1	1.4	CSWDCS	NT	CN
	2	1.0	CSWDCS	CT	VT
	3	13.0	COVER		
7	1	1.0	CSWDCS	NT	CN
8	1	1.0	CSWDCS	NT	VT
	2	13.0	COVER		
	3	7.5	CSWDCS	CT	VT
9	1	1.0	CSWDCS	NT	VT
	2	13.0	COVER		
	3	4.0	CSWDCS	CT	VT
10	1	13.0	COVER		
11	1	2.0	CS	NT	CN
	2	6.0	CSWM	CT	VT
12	1	6.3	COVER		
	2	1.0	CSWDCS	CT	VT
13	1	6.0	COVER		
	2	2.5	CSWDCS	CT	VT
	3	1.0	CSWDCS	CT	VT
14	1	6.0	COVER		
	2	6.0	COVER		
	3	2.5	CSWDCS	CT	VT
15	1	1.0	CSWDCS	NT	VT
	2	2.5	CSWDCS	CT	VT
16	1	13.0	COVER		
	2	4.0	CSWDCS	CT	VT
	3	6.0	CSWM	CT	VT

Table 6.4 Management Practices Under the Erosion Tax Policy for an Erosion Tax of $2.00/ton

Transect	LMU	SLOPE (%)	Crop Rotation	Tillage System	Mechanical Control
1	1	13.0	COVER		
	2	4.0	CSWDCS	NT	VT
2	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
3	1	13.0	COVER		
	2	4.0	CSWDCS	NT	VT
4	1	1.4	CSWDCS	CT	VT
	2	13.0	COVER		
5	1	1.4	CSWDCS	CT	VT
	2	1.0	CSWDCS	CT	VT
	3	23.0	COVER		
6	1	1.4	CSWDCS	CT	VT
	2	1.0	CSWDCS	CT	VT
	3	13.0	COVER		
7	1	1.0	CSWDCS	CT	VT
8	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
	3	7.5	CSWDCS	NT	CN
9	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
	3	4.0	CSWDCS	NT	VT
10	1	13.0	COVER		
11	1	2.0	CS	CT	VT
	2	6.0	CSWM	CT	CN
12	1	6.3	COVER		
	2	1.0	CSWDCS	CT	VT
13	1	6.0	CSWM	CT	CN
	2	2.5	CSWDCS	NT	VT
	3	1.0	CSWDCS	CT	VT
14	1	6.0	CSWM	CT	CN
	2	6.0	CSWM	CT	CN
	3	2.5	CSWDCS	NT	VT
15	1	1.0	CSWDCS	CT	VT
	2	2.5	CSWDCS	NT	VT
16	1	13.0	COVER		
	2	4.0	CSWDCS	NT	VT
	3	6.0	CSWM	CT	CN

Table 6.5 Management Practices Under the Erosion Tax Policy for an Erosion Tax of $11.00/ton

Transect	LMU	SLOPE (%)	Crop Rotation	Tillage System	Mechanical Control
1	1	13.0	COVER		
	2	4.0	CSWDCS	NT	CN
2	1	1.0	CSWDCS	NT	VT
	2	13.0	COVER		
3	1	13.0	COVER		
	2	4.0	CSWDCS	NT	CN
4	1	1.4	CSWDCS	NT	VT
	2	13.0	COVER		
5	1	1.4	CSWDCS	NT	VT
	2	1.0	CSWDCS	NT	VT
	3	23.0	COVER		
6	1	1.4	CSWDCS	NT	VT
	2	1.0	CSWDCS	NT	VT
	3	13.0	COVER		
7	1	1.0	CSWDCS	NT	VT
8	1	1.0	CSWDCS	NT	VT
	2	13.0	COVER		
	3	7.5	CSWDCS	NT	CN
9	1	1.0	CSWDCS	NT	VT
	2	13.0	COVER		
	3	4.0	CSWDCS	NT	CN
10	1	13.0	COVER		
11	1	2.0	CS	NT	VT
	2	6.0	COVER		
12	1	6.3	COVER		
	2	1.0	CSWDCS	NT	VT
13	1	6.0	COVER		
	2	2.5	CSWDCS	NT	CN
	3	1.0	CSWDCS	NT	VT
14	1	6.0	COVER		
	2	6.0	COVER		
	3	2.5	CSWDCS	NT	CN
15	1	1.0	CSWDCS	CT	CN
	2	2.5	CSWDCS	NT	CN
16	1	13.0	COVER		
	2	4.0	CSWDCS	NT	CN
	3	6.0	COVER		

Table 6.6 Management Practices Under the Erosion Standard Policy for an Erosion Standard of 3 tons/acre

Transect	LMU	SLOPE (%)	Crop Rotation	Tillage System	Mechanical Control
1	1	13.0	COVER		
	2	4.0	CSWDCS	NT	VT
2	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
3	1	13.0	COVER		
	2	4.0	CSWDCS	NT	VT
4	1	1.4	CSWDCS	CT	VT
	2	13.0	COVER		
5	1	1.4	CSWDCS	CT	VT
	2	1.0	CSWDCS	CT	VT
	3	23.0	COVER		
6	1	1.4	CSWDCS	CT	VT
	2	1.0	CSWDCS	CT	VT
	3	13.0	COVER		
7	1	1.0	CSWDCS	CT	VT
8	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
	3	7.5	CSWDCS	NT	CN
9	1	1.0	CSWDCS	CT	VT
	2	13.0	COVER		
	3	4.0	CSWDCS	NT	VT
10	1	13.0	COVER		
11	1	2.0	CS	CT	VT
	2	6.0	CSWDCS	NT	CN
12	1	6.3	CSWDCS	NT	CN
	2	1.0	CSWDCS	CT	VT
13	1	6.0	CSWDCS	NT	CN
	2	2.5	CSWDCS	CT	CN
	3	1.0	CSWDCS	CT	VT
14	1	6.0	CSWDCS	NT	CN
	2	6.0	CSWDCS	NT	CN
	3	2.5	CSWDCS	CT	CN
15	1	1.0	CSWDCS	CT	VT
	2	2.5	CSWDCS	CT	CN
16	1	13.0	COVER		
	2	4.0	CSWDCS	NT	VT
	3	6.0	CSWDCS	NT	CN

Table 6.7 Management Practices Under the Erosion Standard Policy for an Erosion Standard of 1 ton/acre

Transect	LMU	SLOPE (%)	Crop Rotation	Tillage System	Mechanical Control
1	1	13.0	COVER		
	2	4.0	CSWDCS	NT	CN
2	1	1.0	CSWDCS	NT	VT
	2	13.0	COVER		
3	1	13.0	COVER		
	2	4.0	CSWDCS	NT	CN
4	1	1.4	CSWDCS	NT	VT
	2	13.0	COVER		
5	1	1.4	CSWDCS	NT	VT
	2	1.0	CSWDCS	NT	VT
	3	23.0	COVER		
6	1	1.4	CSWDCS	NT	VT
	2	1.0	CSWDCS	NT	VT
	3	13.0	COVER		
7	1	1.0	CSWDCS	NT	VT
8	1	1.0	CSWDCS	NT	VT
	2	13.0	COVER		
	3	7.5	COVER		
9	1	1.0	CSWDCS	NT	VT
	2	13.0	COVER		
	3	4.0	CSWDCS	NT	CN
10	1	13.0	COVER		
11	1	2.0	CS	NT	VT
	2	6.0	COVER		
12	1	6.3	COVER		
	2	1.0	CSWDCS	NT	VT
13	1	6.0	COVER		
	2	2.5	CSWDCS	NT	CN
	3	1.0	CSWDCS	NT	VT
14	1	6.0	COVER		
	2	6.0	COVER		
	3	2.5	CSWDCS	NT	CN
15	1	1.0	CSWDCS	CT	CN
	2	2.5	CSWDCS	NT	CN
16	1	13.0	COVER		
	2	4.0	CSWDCS	NT	CN
	3	6.0	COVER		

Table 6.8 Changes in Management Practices under the Three Management Policies Relative to the Unconstrained Sediment Case

Management Policy	Limitation	% Acres Changes of Management Practices					Required Number of LMUs that Change	Number of Changes in the Management Practices of LMUs Adjacent to the Stream	% Change in Management Practices of LMUs Adjacent to the Stream	Total Relative Revenue Reduction $/annum
		Crop Rotation	Tillage System	Mechanical Erosion Control	Tillage and Mechanical Erosion Control	Total				
Least Cost	Unconstrained	-	-	-	-	-	-	-	-	-
	262 tons/annum	2.5	0.4	9.5	0.0	12.4	4	4	100.0	120.00
	48 tons/annum	10.0	41.0	13.4	13.4	51.0	13	12	92.3	1,330.00
Erosion Tax	$2.00/ton	2.5	25.8	11.3	0.6	39.0	13	3	23.0	550.00
	$11.00/ton	13.3	77.1	35.4	25.8	100.0	27	12	44.4	1,977.00
Erosion Standard	3 tons/acre	13.2	28.2	24.8	13.9	52.3	14	3	21.4	919.00
	1 ton/acre	13.9	76.5	33.6	25.2	98.8	27	12	44.4	3,280.00

Table 6.9 Sensitivity Indices for the Input Parameters under the Watershed Based Classification and the Least Cost Policy for an Unconstrained Sediment Load

Transect	LMU	s^{R}	s^{Yc}	s^{Ym}	s^{Ys}	s^{Yw}	s^{Yd}	s^{PRc}	s^{PRm}	s^{PRs}	s^{PRw}
1	1	-	-	-	-	-	-	-	-	-	-
	2	1.52	0.75	0.93	0.53	0.41	0.48	1.91	0.41	1.02	0.99
2	1	3.74	1.16	0.78	0.41	0.86	0.55	1.28	0.79	1.80	1.13
	2	-	-	-	-	-	-	-	-	-	-
3	1	-	-	-	-	-	-	-	-	-	-
	2	1.52	0.75	0.93	0.53	0.41	0.48	1.91	0.41	1.02	0.99
4	1	3.69	0.56	0.52	0.93	0.71	0.74	1.46	0.70	1.00	0.92
	2	-	-	-	-	-	-	-	-	-	-
5	1	3.25	0.56	0.52	0.93	0.71	0.74	1.86	0.70	1.00	0.92
	2	3.92	1.17	0.80	0.71	0.62	0.66	1.75	0.54	1.46	0.95
	3	-	-	-	-	-	-	-	-	-	-
6	1	3.13	0.57	0.52	0.89	0.75	0.79	1.84	0.77	1.36	0.97
	2	3.78	1.19	0.80	0.71	0.60	0.67	1.75	0.41	1.46	1.05
	3	-	-	-	-	-	-	-	-	-	-
7	1	3.71	1.13	0.79	0.75	0.62	0.72	1.60	0.81	1.22	1.11
8	1	3.74	1.16	0.77	0.72	0.64	0.70	1.68	0.79	1.40	1.13
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-
9	1	3.71	1.18	0.75	0.62	0.58	0.63	1.73	0.81	1.02	1.11
	2	-	-	-	-	-	-	-	-	-	-
	3	1.44	0.96	0.49	0.59	0.45	0.52	1.01	0.52	1.13	1.20
10	1	-	-	-	-	-	-	-	-	-	-
11	1	4.19	0.94	0.39	0.60	0.41	0.87	1.31	0.48	1.02	0.73
	2	2.12	0.77	0.68	1.02	0.45	0.40	1.02	0.70	1.47	1.15
12	1	-	-	-	-	-	-	-	-	-	-
	2	4.12	1.16	0.71	0.54	0.54	0.69	1.66	0.36	1.09	1.36
13	1	2.20	0.77	0.68	0.99	0.45	0.45	1.73	0.70	0.47	0.73
	2	2.19	0.45	0.83	0.95	0.47	0.70	1.43	0.52	1.51	0.90
	3	3.80	0.78	0.63	0.98	1.47	0.76	1.07	0.65	1.18	0.97
14	1	2.20	0.52	0.77	0.68	0.72	0.45	1.80	0.73	0.70	0.47
	2	2.24	0.52	0.77	0.68	0.72	0.45	1.80	0.72	0.70	0.47
	3	1.78	0.92	0.83	0.92	0.47	0.46	1.48	0.50	1.45	0.86
15	1	5.15	0.35	0.83	0.75	0.96	0.76	1.03	0.43	1.00	0.60
	2	1.89	0.92	0.83	0.92	0.46	0.46	1.48	0.59	1.44	0.92
16	1	-	-	-	-	-	-	-	-	-	-
	2	2.21	0.75	0.93	0.61	0.73	0.79	1.07	0.48	1.12	1.15
	3	2.02	0.64	0.50	0.78	0.58	0.87	1.70	0.47	0.72	0.55

Table 6.10 Sensitivity Indices for the Input Parameters under the Watershed Based Classification and the Least Cost Policy for a Sediment Load Limitation of 262 tons/annum

Transect	LMU	s^{R}	s^{Yc}	s^{Ym}	s^{Ys}	s^{Yw}	s^{Yd}	s^{PRc}	s^{PRm}	s^{PRs}	s^{PRw}
1	1	-	-	-	-	-	-	-	-	-	-
	2	1.54	0.76	0.62	0.91	0.48	0.74	1.79	0.49	1.02	0.99
2	1	3.89	1.18	0.75	0.62	0.58	0.63	1.14	0.73	1.60	1.13
	2	-	-	-	-	-	-	-	-	-	-
3	1	-	-	-	-	-	-	-	-	-	-
	2	1.54	0.76	0.62	0.91	0.48	0.74	1.79	0.49	1.02	0.93
4	1	4.09	0.46	052	0.63	0.71	0.64	1.04	0.70	1.00	1.02
	2	-	-	-	-	-	-	-	-	-	-
5	1	4.13	0.46	0.52	0.63	0.76	0.64	1.04	0.70	1.00	1.02
	2	3.68	2.17	0.80	0.71	0.62	0.66	1.75	0.54	1.46	0.95
	3	-	-	-	-	-	-	-	-	-	-
6	1	4.13	0.47	0.49	0.60	0.77	0.55	1.02	0.77	1.36	0.98
	2	3.78	2.14	0.83	0.94	0.57	0.81	1.69	0.59	1.36	1.05
	3	-	-	-	-	-	-	-	-	-	-
7	1	3.71	1.08	0.75	0.62	0.57	0.62	1.70	0.61	1.12	1.11
8	1	3.74	1.38	0.75	0.62	0.58	0.63	1.73	0.60	1.04	1.13
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-
9	1	3.89	1.38	0.75	0.62	0.58	0.63	1.73	0.60	1.04	1.12
	2	-	-	-	-	-	-	-	-	-	-
	3	1.44	0.99	0.49	0.59	0.45	0.52	1.01	0.55	1.13	1.20
10	1	-	-	-	-	-	-	-	-	-	-
11	1	4.19	0.95	0.33	0.65	0.46	0.78	1.02	0.44	1.00	0.67
	2	2.29	0.77	0.68	1.02	0.45	0.80	1.02	0.70	1.47	1.15
12	1	-	-	-	-	-	-	-	-	-	-
	2	4.93	1.50	0.41	0.66	0.73	0.47	1.60	0.36	1.09	1.36
13	1	2.20	0.76	0.79	0.91	0.59	0.84	1.73	0.70	0.55	0.58
	2	1.89	0.55	0.36	0.94	0.62	0.73	1.23	0.55	1.41	0.92
	3	2.90	0.67	0.63	0.98	1.47	0.76	1.07	0.65	1.18	0.97
14	1	2.20	0.77	0.39	0.71	0.92	0.90	1.42	0.35	0.63	0.58
	2	2.24	0.64	0.50	0.78	1.12	0.89	1.47	0.35	0.63	0.58
	3	1.78	0.58	0.48	0.90	0.49	0.73	1.58	0.50	1.05	0.77
15	1	6.35	0.45	0.48	0.90	1.12	0.85	1.01	0.42	0.89	0.62
	2	1.89	0.92	0.43	0.92	0.47	0.48	1.48	0.49	1.44	0.90
16	1	-	-	-	-	-	-	-	-	-	-
	2	2.25	0.94	0.54	0.81	0.60	0.87	1.05	0.62	1.02	1.15
	3	2.12	0.68	0.42	0.76	0.39	0.91	1.74	0.62	0.78	0.44

Table 6.11 Sensitivity Indices for the Input Parameters under the Watershed Based Classification and the Least Cost Policy for a Sediment Load Limitation of 48 tons/annum

Transect	LMU	s^{R}	s^{Yc}	s^{Ym}	s^{Ys}	s^{Yw}	s^{Yd}	s^{PRc}	s^{PRm}	s^{PRs}	s^{PRw}
1	1	-	-	-	-	-	-	-	-	-	-
	2	1.52	1.08	0.97	0.91	0.48	0.74	1.83	0.49	1.02	0.77
2	1	4.99	1.26	0.77	0.81	0.73	0.96	1.83	0.49	1.52	1.12
	2	-	-	-	-	-	-	-	-	-	-
3	1	-	-	-	-	-	-	-	-	-	-
	2	1.52	1.08	0.97	0.91	0.48	0.74	1.83	0.49	1.02	0.77
4	1	5.53	0.96	0.79	0.75	0.97	0.80	1.54	0.82	1.39	1.26
	2	-	-	-	-	-	-	-	-	-	-
5	1	5.11	0.82	0.79	0.98	0.77	0.87	1.40	0.80	1.28	1.09
	2	3.92	3.18	0.83	0.94	0.57	0.81	2.15	0.59	1.75	0.91
	3	-	-	-	-	-	-	-	-	-	-
6	1	7.21	0.87	0.69	0.94	0.82	0.88	1.13	0.96	1.06	1.03
	2	3.95	3.17	0.81	0.92	0.48	0.76	2.12	0.58	1.78	0.94
	3	-	-	-	-	-	-	-	-	-	-
7	1	5.60	3.27	0.74	0.73	0.48	0.69	1.48	0.47	1.29	0.74
8	1	5.24	3.52	0.73	0.68	0.78	0.68	1.86	0.51	1.44	0.85
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-
9	1	5.24	3.52	0.72	0.68	0.78	0.68	1.86	0.51	1.44	0.85
	2	-	-	-	-	-	-	-	-	-	-
	3	1.44	2.10	0.91	0.92	0.52	0.78	1.82	0.49	1.43	0.90
10	1	-	-	-	-	-	-	-	-	-	-
11	1	6.47	1.75	0.77	0.75	0.54	0.46	1.06	0.67	0.87	0.75
	2	2.17	0.95	0.71	1.09	0.55	0.83	1.12	0.95	1.55	1.06
12	1	-	-	-	-	-	-	-	-	-	-
	2	4.93	1.30	0.61	0.81	0.73	0.67	1.60	0.36	1.09	1.36
13	1	2.25	0.88	0.38	0.66	0.47	0.66	0.73	0.70	0.55	0.58
	2	1.78	0.79	0.44	0.92	0.35	0.73	1.46	0.50	1.51	0.86
	3	4.19	1.69	0.56	0.84	1.35	0.97	1.79	0.55	1.65	1.68
14	1	3.27	0.36	0.54	0.70	0.82	0.58	0.67	0.35	0.63	0.58
	2	2.39	0.80	1.63	0.67	0.50	0.40	1.46	0.61	1.46	1.04
	3	2.46	0.74	0.68	0.68	0.46	0.74	0.48	0.44	1.51	0.59
15	1	7.27	0.99	0.83	0.53	1.60	0.58	1.26	0.29	1.00	1.05
	2	2.12	0.92	0.43	0.92	0.47	0.46	0.48	0.44	1.52	0.83
16	1	-	-	-	-	-	-	-	-	-	-
	2	2.21	2.04	0.46	0.50	0.61	0.50	1.85	0.63	1.38	1.14
	3	2.02	0.94	2.59	1.05	0.55	0.97	1.36	0.61	1.42	1.14

Table 6.12 Sensitivity Indices for the Input Parameters under the Watershed Based Classification and the Erosion Tax Policy for an Erosion Tax of $2.00/ton

Transect	LMU	s^R	s^{Yc}	s^{Ym}	s^{Ys}	s^{Yw}	s^{Yd}	s^{PRc}	s^{PRm}	s^{PRs}	s^{PRw}
1	1	-	-	-	-	-	-	-	-	-	-
	2	3.70	0.91	0.70	0.91	0.77	0.69	2.19	0.55	1.73	1.55
2	1	3.79	1.08	0.75	0.62	0.58	0.63	2.28	0.74	1.80	1.08
	2	-	-	-	-	-	-	-	-	-	-
3	1	-	-	-	-	-	-	-	-	-	-
	2	3.70	0.91	0.70	0.91	0.77	0.69	2.19	0.55	1.73	1.55
4	1	4.06	0.56	0.72	0.53	0.59	0.44	1.92	0.63	1.89	1.22
	2	-	-	-	-	-	-	-	-	-	-
5	1	4.09	0.56	0.72	0.53	0.59	0.44	1.04	0.70	1.22	1.32
	2	3.71	1.15	0.80	0.71	0.62	0.66	2.23	0.63	1.78	1.02
	3	-	-	-	-	-	-	-	-	-	-
6	1	4.06	0.56	0.72	0.53	0.59	0.44	1.04	0.70	1.22	1.32
	2	3.71	1.15	0.80	0.71	0.62	0.66	2.23	0.63	1.78	1.02
	3	-	-	-	-	-	-	-	-	-	-
7	1	3.75	1.38	0.54	0.53	0.52	0.47	2.30	0.76	1.82	1.06
8	1	3.79	1.08	0.75	0.62	0.58	0.63	2.28	0.74	1.80	1.08
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-
9	1	3.75	1.08	0.75	0.62	0.58	0.63	2.28	0.76	1.82	1.06
	2	-	-	-	-	-	-	-	-	-	-
	3	3.45	0.90	0.71	0.76	0.72	0.71	2.20	0.59	1.71	1.60
10	1	-	-	-	-	-	-	-	-	-	-
11	1	4.15	1.51	0.63	0.48	0.47	0.66	2.30	0.51	0.96	0.62
	2	2.23	0.76	1.12	1.53	0.59	0.84	2.06	1.58	1.53	1.14
12	1	-	-	-	-	-	-	-	-	-	-
	2	4.92	1.29	0.62	0.59	0.78	0.59	1.67	0.55	1.71	1.61
13	1	2.48	0.76	1.39	1.53	0.59	0.84	2.12	1.40	1.49	1.14
	2	2.77	0.49	0.74	1.05	0.96	0.92	1.65	0.40	1.73	1.39
	3	4.58	0.93	0.51	0.69	1.24	0.66	1.74	0.59	1.26	1.39
14	1	2.48	0.58	1.34	1.79	0.59	0.84	2.12	1.40	1.49	1.14
	2	2.48	0.58	1.34	1.79	0.59	0.84	2.12	1.40	1.49	1.14
	3	2.60	0.49	0.76	1.10	0.86	0.98	1.64	0.44	1.80	1.50
15	1	6.35	0.43	0.96	0.67	0.93	0.59	1.58	0.40	1.33	1.01
	2	2.78	0.49	0.74	1.05	0.96	0.92	1.62	0.36	1.75	1.75
16	1	-	-	-	-	-	-	-	-	-	-
	2	5.23	0.93	0.78	0.93	0.70	1.31	2.34	0.63	1.59	1.51
	3	1.39	0.91	1.10	1.83	0.47	0.68	2.11	1.81	1.52	1.17

Table 6.13 Sensitivity Indices for the Input Parameters under the Watershed Based Classification and the Erosion Tax Policy for an Erosion Tax of $11.00/ton

Transect	LMU	s^{R}	s^{Yc}	s^{Ym}	s^{Ys}	s^{Yw}	s^{Yd}	s^{PRc}	s^{PRm}	s^{PRs}	s^{PRw}
1	1	-	-	-	-	-	-	-	-	-	-
	2	6.00	0.92	0.79	0.72	0.61	0.78	1.73	0.53	1.65	1.40
2	1	5.02	0.92	0.74	0.73	0.85	0.93	1.85	0.44	1.54	0.84
	2	-	-	-	-	-	-	-	-	-	-
3	1	-	-	-	-	-	-	-	-	-	-
	2	6.00	0.92	0.79	0.72	0.61	0.78	1.73	0.53	1.65	1.40
4	1	5.60	0.87	0.57	0.66	0.69	0.98	1.54	0.90	1.51	1.24
	2										
5	1	4.54	0.85	0.57	0.66	0.71	0.76	1.79	0.80	1.53	1.31
	2	4.42	1.04	0.68	0.99	0.99	0.96	1.87	0.30	1.73	1.15
	3	-	-	-	-	-	-	-	-	-	-
6	1	4.54	0.80	0.57	0.66	0.71	0.76	1.79	0.80	1.53	1.31
	2	4.42	1.04	0.68	0.99	0.99	0.96	1.87	0.30	1.73	1.15
	3	-	-	-	-	-	-	-	-	-	-
7	1	5.29	0.92	0.68	0.73	0.85	0.93	1.86	0.46	1.47	0.85
8	1	5.29	0.92	0.68	0.73	0.85	0.93	1.86	0.46	1.47	0.85
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-
9	1	5.29	0.92	0.68	0.73	0.85	0.93	1.86	0.46	1.47	0.85
	2	-	-	-	-	-	-	-	-	-	-
	3	3.75	0.85	0.91	0.85	0.97	0.51	1.93	0.67	1.84	1.58
10	1	-	-	-	-	-	-	-	-	-	-
11	1	6.14	1.45	0.76	0.50	0.62	0.67	2.18	0.59	0.79	0.87
	2	-	-	-	-	-	-	-	-	-	-
12	1	-	-	-	-	-	-	-	-	-	-
	2	7.12	1.01	0.63	0.60	0.56	0.36	1.36	0.44	1.48	1.68
13	1	-	-	-	-	-	-	-	-	-	-
	2	4.49	0.99	0.72	0.33	0.51	0.23	1.74	0.32	1.81	1.40
	3	5.17	0.98	0.66	0.77	0.82	0.66	1.70	0.42	1.31	1.45
14	1	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-
	3	4.14	0.96	0.58	0.38	0.57	0.35	1.83	0.47	1.88	1.31
15	1	7.43	0.60	0.71	0.69	1.22	0.57	1.19	0.35	0.97	0.90
	2	3.86	0.92	0.74	0.39	0.55	0.71	1.39	0.55	1.70	1.03
16	1	-	-	-	-	-	-	-	-	-	-
	2	6.25	0.98	0.57	0.63	0.58	0.83	1.85	0.53	1.64	1.39
	3	-	-	-	-	-	-	-	-	-	-

Table 6.14 Sensitivity Indices for the Input Parameters under the Farm Based Classification and the Erosion Standard Policy for an Erosion Standard of 3 tons/acre

Transect	LMU	s^{R}	s^{Yc}	s^{Ym}	s^{Ys}	s^{Yw}	s^{Yd}	s^{PRc}	s^{PRm}	s^{PRs}	s^{PRw}
1	1	-	-	-	-	-	-	-	-	-	-
	2	3.80	4.36	0.40	2.59	3.81	1.36	2.12	0.60	1.64	1.36
2	1	3.86	3.40	0.92	2.36	2.24	1.42	2.29	0.81	1.81	1.12
	2	-	-	-	-	-	-	-	-	-	-
3	1	-	-	-	-	-	-	-	-	-	-
	2	3.80	4.36	0.40	2.59	3.81	1.36	2.12	0.60	1.64	1.36
4	1	4.22	3.33	0.56	2.41	2.52	0.94	1.92	0.57	1.80	1.12
	2	-	-	-	-	-	-	-	-	-	-
5	1	4.22	3.33	0.56	2.41	2.52	0.94	1.92	0.57	1.80	1.12
	2	3.86	3.40	0.92	2.36	2.24	1.42	2.29	0.81	1.81	1.12
	3	-	-	-	-	-	-	-	-	-	-
6	1	4.22	3.33	0.56	2.41	2.52	0.94	1.92	0.57	1.80	1.12
	2	3.86	3.40	0.92	2.36	2.24	1.42	2.29	0.81	1.81	1.12
	3	-	-	-	-	-	-	-	-	-	-
7	1	3.86	3.40	0.92	2.36	2.24	1.42	2.29	0.81	1.81	1.12
8	1	3.86	3.40	0.92	2.36	2.24	1.42	2.29	0.81	1.81	1.12
	2	-	-	-	-	-	-	-	-	-	-
	3	1.96	3.76	0.47	2.71	2.99	0.85	2.08	0.38	1.58	1.23
9	1	3.86	3.40	0.92	2.36	2.24	1.42	2.29	0.81	1.81	1.12
	2	-	-	-	-	-	-	-	-	-	-
	3	3.80	4.36	0.40	2.59	3.81	1.36	2.12	0.60	1.64	1.36
10	1	-	-	-	-	-	-	-	-	-	-
11	1	4.30	4.41	0.69	2.74	0.95	0.73	2.32	0.43	1.04	0.71
	2	2.06	3.34	0.49	4.05	3.04	0.67	2.27	0.59	1.44	1.76
12	1	1.29	3.70	0.97	2.98	2.11	1.08	1.80	0.70	1.78	2.05
	2	4.44	3.83	0.45	2.89	2.95	0.94	1.59	0.47	1.82	1.61
13	1	2.06	3.34	0.49	4.05	3.04	0.67	2.27	0.59	1.44	1.76
	2	2.58	2.29	0.64	2.61	2.16	0.54	1.81	0.61	2.11	1.19
	3	5.17	3.66	0.49	2.24	3.35	1.67	1.88	0.52	1.48	1.53
14	1	2.06	3.34	0.49	4.05	3.04	0.67	2.27	0.59	1.44	1.76
	2	2.06	3.34	0.49	4.05	3.04	0.67	2.27	0.59	1.44	1.76
	3	2.58	2.29	0.64	2.61	2.16	0.54	1.81	0.61	2.11	1.19
15	1	6.54	2.79	0.97	2.08	2.27	1.18	1.54	0.35	1.27	1.00
	2	2.58	2.29	0.64	2.61	2.16	0.54	1.81	0.61	2.11	1.19
16	1	-	-	-	-	-	-	-	-	-	-
	2	3.80	4.36	0.40	2.59	3.81	1.36	2.12	0.60	1.64	1.36
	3	2.06	3.34	0.49	4.05	3.04	0.67	2.27	0.59	1.44	1.76

Table 6.15 Sensitivity Indices for Input Parameters under the Farm Based Classification and the Erosion Standard Policy for an Erosion Standard of 1 ton/acre

Transect	LMU	s^R	s^{Yc}	s^{Ym}	s^{Ys}	s^{Yw}	s^{Yd}	s^{PRc}	s^{PRm}	s^{PRs}	s^{PRw}
1	1	-	-	-	-	-	-	-	-	-	-
	2	5.13	3.48	0.47	2.43	3.79	1.04	1.51	0.75	1.53	0.98
2	1	5.42	3.59	0.63	2.74	3.77	1.65	1.84	0.52	1.45	0.82
	2	-	-	-	-	-	-	-	-	-	-
3	1	-	-	-	-	-	-	-	-	-	-
	2	5.13	3.48	0.47	2.43	3.79	1.04	1.51	0.75	1.53	0.98
4	1	5.48	4.27	0.85	2.07	3.99	1.22	1.53	0.70	1.40	1.24
	2	-	-	-	-	-	-	-	-	-	-
5	1	5.48	4.27	0.85	2.07	3.99	1.22	1.53	0.70	1.40	1.24
	2	5.42	3.59	0.63	2.74	3.77	1.65	1.84	0.52	1.45	0.82
	3	-	-	-	-	-	-	-	-	-	-
6	1	5.48	4.27	0.85	2.07	3.99	1.22	1.53	0.70	1.40	1.24
	2	5.42	3.59	0.63	2.74	3.77	1.65	1.84	0.52	1.45	0.82
	3	-	-	-	-	-	-	-	-	-	-
7	1	5.42	3.59	0.63	2.74	3.77	1.65	1.84	0.52	1.45	0.82
8	1	5.42	3.59	0.63	2.74	3.77	1.65	1.84	0.52	1.45	0.82
	2	-	-	-	-	-	-	-	-	-	-
	3	2.05	0.21	0.32	0.24	0.33	0.11	0.16	0.35	0.11	0.24
9	1	5.42	3.59	0.63	2.74	3.77	1.65	1.84	0.52	1.45	0.82
	2	-	-	-	-	-	-	-	-	-	-
	3	5.13	3.48	0.47	2.43	3.79	1.04	1.51	0.75	1.53	0.98
10	1	-	-	-	-	-	-	-	-	-	-
11	1	6.12	4.81	0.71	2.49	0.82	0.95	2.20	0.46	0.82	0.62
	2	3.10	0.04	0.11	0.02	0.08	0.14	0.11	0.22	0.29	0.17
12	1	1.75	0.34	0.46	0.15	0.52	0.35	0.25	0.47	0.33	0.53
	2	5.79	3.59	0.97	2.91	4.08	0.83	1.10	0.53	1.39	1.61
13	1	3.10	0.04	0.11	0.02	0.08	0.14	0.11	0.22	0.29	0.17
	2	3.75	3.07	0.68	2.99	4.25	0.80	1.46	0.58	1.71	1.16
	3	6.77	3.30	0.78	1.87	3.74	1.08	1.70	0.47	0.92	1.22
14	1	3.10	0.04	0.11	0.02	0.08	0.14	0.11	0.22	0.29	0.17
	2	3.10	0.04	0.11	0.02	0.08	0.14	0.11	0.22	0.29	0.17
	3	3.75	3.07	0.68	2.99	4.25	0.80	1.46	0.58	1.71	1.16
15	1	7.67	2.19	0.76	1.70	2.20	0.73	1.07	0.35	0.94	0.78
	2	3.75	3.07	0.68	2.99	4.25	0.80	1.46	0.58	1.71	1.16
16	1	-	-	-	-	-	-	-	-	-	-
	2	5.13	3.48	0.47	2.43	3.79	1.04	1.51	0.75	1.53	0.98
	3	3.10	0.04	0.11	0.02	0.08	0.14	0.11	0.22	0.29	0.17

Table 6.16 Sensitivity Indices for Input Parameters under the Farm Based Classification and the Erosion Tax Policy for an Erosion Tax of $2.00/ton

Transect	LMU	s^R	s^{Yc}	s^{Ym}	s^{Ys}	s^{Yw}	s^{Yd}	s^{PRc}	s^{PRm}	s^{PRs}	s^{PRw}
1	1	-	-	-	-	-	-	-	-	-	-
	2	3.80	4.32	0.36	2.59	3.85	1.32	2.17	0.64	1.65	1.31
2	1	3.90	3.44	0.78	2.36	2.24	1.42	2.29	0.78	1.81	1.08
	2	-	-	-	-	-	-	-	-	-	-
3	1	-	-	-	-	-	-	-	-	-	-
	2	3.80	4.32	0.36	2.59	3.85	1.32	2.17	0.64	1.65	1.31
4	1	4.19	3.32	0.54	2.35	2.53	0.92	1.93	0.62	1.88	1.21
	2	-	-	-	-	-	-	-	-	-	-
5	1	4.19	3.32	0.54	2.35	2.53	0.92	1.93	0.62	1.88	1.21
	2	3.90	3.44	0.78	2.36	2.24	1.42	2.29	0.78	1.81	1.08
	3	-	-	-	-	-	-	-	-	-	-
6	1	4.19	3.32	0.54	2.35	2.53	0.92	1.93	0.62	1.88	1.21
	2	3.90	3.44	0.78	2.36	2.24	1.42	2.29	0.78	1.81	1.08
	3	-	-	-	-	-	-	-	-	-	-
7	1	3.90	3.44	0.78	2.36	2.24	1.42	2.29	0.78	1.81	1.08
8	1	3.90	3.44	0.78	2.36	2.24	1.42	2.29	0.78	1.81	1.08
	2	-	-	-	-	-	-	-	-	-	-
	3	2.06	3.71	0.52	2.66	2.99	0.85	2.13	0.43	1.53	1.18
9	1	3.90	3.44	0.78	2.36	2.24	1.42	2.29	0.78	1.81	1.08
	2	-	-	-	-	-	-	-	-	-	-
	3	3.80	4.32	0.36	2.59	3.85	1.32	2.17	0.64	1.65	1.31
10	1	-	-	-	-	-	-	-	-	-	-
11	1	4.25	4.47	0.69	2.72	0.89	0.73	2.30	0.47	0.98	0.60
	2	2.53	2.33	2.79	3.54	2.45	0.89	2.12	1.38	1.49	1.13
12	1	1.19	0.14	0.21	0.17	0.31	0.11	0.14	0.22	0.10	0.27
	2	4.50	3.76	0.40	2.90	3.00	0.95	1.68	0.46	1.93	1.67
13	1	2.53	2.33	2.79	3.54	2.45	0.89	2.12	1.38	1.49	1.13
	2	2.88	2.81	0.64	2.89	3.49	0.65	1.63	0.41	1.76	1.40
	3	5.13	3.65	0.46	2.19	3.40	1.68	1.90	0.50	1.51	1.60
14	1	2.53	2.33	2.79	3.54	2.45	0.89	2.12	1.38	1.49	1.13
	2	2.53	2.33	2.79	3.54	2.45	0.89	2.12	1.38	1.49	1.13
	3	2.88	2.81	0.64	2.89	3.49	0.65	1.63	0.41	1.76	1.40
15	1	6.54	2.83	0.81	2.04	2.32	1.13	1.58	0.39	1.27	1.00
	2	2.88	2.81	0.64	2.89	3.49	0.65	1.63	0.41	1.76	1.40
16	1	-	-	-	-	-	-	-	-	-	-
	2	3.80	4.32	0.36	2.59	3.85	1.32	2.17	0.64	1.65	1.31
	3	2.53	2.33	2.79	3.54	2.45	0.89	2.12	1.38		

Table 6.17 Sensitivity Indices for Input Parameters under the Farm Based Classification and the Erosion Tax Policy for an Erosion Tax of $11.00/ton

Transect	LMU	s^{R}	s^{Yc}	s^{Ym}	s^{Ys}	s^{Yw}	s^{Yd}	s^{PRc}	s^{PRm}	s^{PRs}	s^{PRw}
1	1	-	-	-	-	-	-	-	-	-	-
	2	4.99	3.54	0.38	2.49	3.93	0.98	1.57	0.70	1.57	0.86
2	1	5.46	3.59	0.59	2.78	3.72	1.61	1.84	0.52	1.48	0.82
	2	-	-	-	-	-	-	-	-	-	-
3	1	-	-	-	-	-	-	-	-	-	-
	2	4.99	3.54	0.38	2.49	3.93	0.98	1.57	0.70	1.57	0.86
4	1	5.57	4.38	0.82	2.11	3.92	1.17	1.52	0.79	1.54	1.24
	2	-	-	-	-	-	-	-	-	-	-
5	1	5.57	4.38	0.82	2.11	3.92	1.17	1.52	0.79	1.54	1.24
	2	5.46	3.59	0.59	2.78	3.72	1.61	1.84	0.52	1.48	0.82
	3	-	-	-	-	-	-	-	-	-	-
6	1	5.57	4.38	0.82	2.11	3.92	1.17	1.52	0.79	1.54	1.24
	2	5.46	3.59	0.59	2.78	3.72	1.61	1.84	0.52	1.48	0.82
	3	-	-	-	-	-	-	-	-	-	-
7	1	5.46	3.59	0.59	2.78	3.72	1.61	1.84	0.52	1.48	0.82
8	1	5.46	3.59	0.59	2.78	3.72	1.61	1.84	0.52	1.48	0.82
	2	-	-	-	-	-	-	-	-	-	-
	3	2.54	3.58	0.47	2.55	2.95	0.78	2.34	0.49	1.45	1.09
9	1	5.46	3.59	0.59	2.78	3.72	1.61	1.84	0.52	1.48	0.82
	2	-	-	-	-	-	-	-	-	-	-
	3	4.99	3.54	0.38	2.49	3.93	0.98	1.57	0.70	1.57	0.86
10	1	-	-	-	-	-	-	-	-	-	-
11	1	6.11	4.83	0.71	2.47	0.80	0.92	2.22	0.48	0.80	0.64
	2	2.05	0.13	0.24	0.16	0.32	0.31	0.22	0.31	0.21	0.11
12	1	1.79	0.25	0.33	0.06	0.04	0.26	0.14	0.32	0.17	0.23
	2	5.75	3.51	0.97	3.03	4.11	0.85	1.17	0.51	1.51	1.61
13	1	2.05	0.13	0.24	0.16	0.32	0.31	0.22	0.31	0.21	0.11
	2	3.90	3.05	0.70	3.04	4.28	0.73	1.42	0.50	1.79	1.15
	3	6.78	3.34	0.78	1.86	3.78	1.04	1.79	0.51	0.91	1.21
14	1	2.05	0.13	0.24	0.16	0.32	0.31	0.22	0.31	0.21	0.11
	2	2.05	0.13	0.24	0.16	0.32	0.31	0.22	0.31	0.21	0.11
	3	3.90	3.05	0.70	3.04	4.28	0.73	1.42	0.50	1.79	1.15
15	1	7.63	2.24	0.79	1.68	2.19	0.69	1.22	0.40	0.90	0.88
	2	3.90	3.05	0.70	3.04	4.28	0.73	1.42	0.50	1.79	1.15
16	1	-	-	-	-	-	-	-	-	-	-
	2	4.99	3.54	0.38	2.49	3.93	0.98	1.57	0.70	1.57	0.86
	3	2.05	0.13	0.24	0.16	0.32	0.31	0.22	0.31	0.21	0.11

Table 6.18 Summary of Regret and Robustness Analyses under the Watershed Based Analysis

Input Scenario *(I)*	Sets of Management Practices *(MD)*	Maximum Revenue Regret ($/ annum)	Expected Revenue Regret ($/ annum)	Maximum Sediment Regret (+) (tons/ annum)	Maximum Sediment Regret (-) (tons/ annum)	Expected Sediment Regret (tons/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Sediment <200 tons/ annum (%)	Frequency of Sediment <150 tons/ annum (%)	Frequency of Sediment <100 tons/ annum (%)
7	*7*	6039	2046	183	-50	12.2	75	53	27	95	85	41
19	*19*	6898	2317	205	0	39.7	70	48	17	100	97	80
70	*70*	8108	785	191	-24	22.3	95	89	74	97	93	60

Table 6.19 Alternative Robust Sets of Management Practices under the Watershed Based Analysis

Transect	LMU	Slope (%)	*MD7*	*MD19*	*MD70*
1	1	13.0	COVER	COVER	COVER
	2	4.0	CCSWMMMM CT VT	CCSWMMMM CT VT	CSWDCS NT VT
2	1	1.0	CSWDCS CT CN	CSWDCS NT VT	CSWDCS NT VT
	2	13.0	COVER	COVER	COVER
3	1	13.0	COVER	COVER	COVER
	2	4.0	CCSWMMMM CT VT	CCSWMMMM CT VT	CSWDCS NT VT
4	1	1.4	CSWDCS CT CN	CS CT CN	CS CT CN
	2	13.0	COVER	COVER	COVER
5	1	1.4	CSWDCS NT VT	CS CT CN	CS CT CN
	2	1.0	CSWDCS CT CN	CSWDCS NT VT	CSWDCS NT VT
	3	23.0	COVER	COVER	COVER
6	1	1.4	CSWDCS NT VT	CS CT CN	CS CT CN
	2	1.0	CSWDCS CT CN	CSWDCS NT VT	CSWDCS NT VT
	3	13.0	COVER	COVER	COVER
7	1	1.0	CSWDCS CT CN	CSWDCS NT VT	CSWDCS NT VT
8	1	1.0	CSWDCS CT CN	CSWDCS NT VT	CSWDCS NT VT
	2	13.0	COVER	COVER	COVER
	3	7.5	CS NT CN	CSWDCS NT CN	CSWDCS NT CN
9	1	1.0	CSWDCS CT CN	CSWDCS NT VT	CSWDCS NT VT
	2	13.0	COVER	COVER	COVER
	3	4.0	CCSWMMMM CT VT	CCSWMMMM CT VT	CSWDCS NT VT
10	1	13.0	COVER	COVER	COVER
11	1	2.0	CS CT CN	CSWDCS CT CN	CSWDCS CT CN
	2	6.0	COVER	CSWDCS NT VT	COVER
12	1	6.3	CCSWMMMM NT VT	COVER	CCSWMMMM CT CN
	2	1.0	CSWDCS CT VT	CS CT VT	CSWDCS CT VT
13	1	6.0	COVER	COVER	COVER
	2	2.5	CSWDCS CT CN	CSWDCS CT CN	CSWDCS NT CN
	3	1.0	CSWDCS CT VT	CSWDCS CT VT	CCSWMMMM CT VT
14	1	6.0	COVER	COVER	COVER
	2	6.0	COVER	CSWDCS NT VT	COVER
	3	2.5	CSWDCS CT CN	CCSWMMMM CT CN	CSWDCS NT CN
15	1	1.0	CSWDCS CT CN	CSWDCS NT VT	CSWDCS CT VT
	2	2.5	CSWDCS NT VT	CCSWMMMM CT CN	CSWDCS NT CN
16	1	13.0	COVER	COVER	COVER
	2	4.0	CSWDCS CT CN	CCSWMMMM CT VT	CSWDCS NT VT
	3	6.0	COVER	CSWDCS NT CN	COVER

Table 6.20 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 1 2, LMU 3 2, LMU 9 3, and LMU 16 2

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/ acre/ annum)	Exp Revenue Regret ($/ acre/ annum)	Max Erosion Regret (+) (tons/ acre/ annum)	Max Erosion Regret (-) (tons/ acre/ annum)	Exp Erosion Regret (tons/ acre/ annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/ acre/ annum (%)	Freq of Erosion <1.5 tons/ acre/ annum (%)	Freq of Erosion <1.0 tons/ acre/ annum (%)
1	CSWDCS	NT	VT	82	29.1	1.74	-1.72	-0.34	22	17	7	92	73	36
2	CS	CT	CN	131	68.6	0.28	-8.96	-2.47	6	5	3	11	3	0
3	CSWDCS	CT	CN	124	68.7	0.69	-5.29	-1.67	11	11	8	28	11	1
4	CSWDCS	CT	VT	153	86.6	0*	-11.88	-4.06	6	5	5	1	1	0
5	CCSWMMMM	CT	CN	101	31.6	1.86	-1.20	-0.15	34	30	20	98	90	54
6	CCSWMMMM	CT	VT	124	63.4	1.17	-3.71	-1.02	9	8	4	54	28	10
7	CSWDCS	NT	CN	77*	7.1*	2.14	-0.58*	0.19	82*	76*	71*	100*	99*	92*
8	CS	NT	CN	91	33.7	1.82	-2.07	-0.25	20	12	7	94	78	51
9	CCSWMMMM	NT	VT	101	30.6	1.97	-0.75	-0.02*	36	31	24	98	95	69

Table 6.21 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 2 1, LMU 5 2, LMU 6 2, LMU 7 1, LMU 8 1, and LMU 9 1

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/acre/annum)	Exp Revenue Regret ($/acre/annum)	Max Erosion Regret (+) (tons/acre/annum)	Max Erosion Regret (-) (tons/acre/annum)	Exp Erosion Regret (tons/acre/annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/acre/annum (%)	Freq of Erosion <1.5 tons/acre/annum (%)	Freq of Erosion <1.0 tons/acre/annum (%)
1	CSWDCS	CT	VT	131	63.6	0.32	-3.48	-1.10	13	9	5	75	50	14
2	CS	CT	VT	151	74.7	0.00*	-3.65	-1.50	10	7	3	55	25	10
3	CCSWMMMM	CT	VT	118	53.4	1.10	-0.95	-0.23	15	7	3	100*	100*	94
4	CS	CT	CN	120	48.8	0.56	-1.98	-0.79	18	12	5	90	77	33
5	CSWDCS	CT	CN	77	35.1	0.75	-1.92	-0.55	26	14	11	98	90	61
6	CS	NT	VT	105	31.8	1.17	-1.06	-0.21	37	27	7	100*	99	92
7	CSWDCS	NT	VT	68*	11.5	1.38	-0.34	-0.01*	88	76	22	100*	100*	100*
8	CS	NT	CN	108	24.8	1.39	-0.52	-0.02	49	39	29	100*	100*	100*
9	CSWDCS	NT	CN	71	5.3*	1.59	-0.04*	0.10	93*	84*	74*	100*	100*	100*
10	CCSWMMMM	NT	VT	105	43.7	1.63	-0.06	0.09	24	19	14	100*	100*	100*

Table 6.22 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 4 1, LMU 5 1, and LMU 6 1

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/acre/annum)	Exp Revenue Regret ($/acre/annum)	Max Erosion Regret (+) (tons/acre/annum)	Max Erosion Regret (-) (tons/acre/annum)	Exp Erosion Regret (tons/acre/annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/acre/annum (%)	Freq of Erosion <1.5 tons/acre/annum (%)	Freq of Erosion <1.0 tons/acre/annum (%)
1	CSWDCS	CT	VT	245	84.9	0.24	-4.35	-1.29	13	9	6	63	35	10
2	CS	CT	VT	201	89.5	0.00*	-5.31	-1.64	11	10	5	46	20	7
3	CS	CT	CN	145	56.2	0.55	-2.81	-0.86	20	13	9	87	68	29
4	CCSWMMMM	CT	VT	160	59.2	1.15	-0.93	-0.26	15	11	7	100*	99	91
5	CSWDCS	CT	CN	155	47.0	0.72	-2.23	-0.65	27	17	8	97	82	45
6	CS	NT	CN	93	20.8	1.54	-0.99	0.01*	64	46	37	100*	100*	99
7	CSWDCS	NT	VT	75	16.8	1.42	-0.39	-0.03	80	66	22	100*	100*	99
8	CS	NT	VT	102	29.6	1.26	-1.99	-0.19	50	32	11	99	98	94
9	CCSWMMMM	CT	CN	143	50.0	1.41	-0.31	-0.03	29	21	15	100*	100*	99
10	CSWDCS	NT	CN	70*	9.4*	1.73	-0.07*	0.10	86*	78*	63*	100*	100*	100*

Table 6.23 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 8 3

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/acre/annum)	Exp Revenue Regret ($/acre/annum)	Max Erosion Regret (+) (tons/acre/annum)	Max Erosion Regret (-) (tons/acre/annum)	Exp Erosion Regret (tons/acre/annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/acre/annum (%)	Freq of Erosion <1.5 tons/acre/annum (%)	Freq of Erosion <1.0 tons/acre/annum (%)
1	CSWDCS	NT	CN	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
2	CS	NT	CN	77	29.2	1.31*	-12.01	-2.91	7	5	3	10	3	1
3	CCSWMMMM	CT	CN	78	32.9	1.66	-6.23	-1.29	7	6	5	26	13	3
4	COVER			129	19.6	2.56	0.00*	0.77	0	0	0	100*	100*	100*
5	CCSWMMMM	NT	CN	61*	14.2*	2.18	-2.71	-0.07*	31*	31*	31*	93	72	30

Table 6.24 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 11 1

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/ acre/ annum)	Exp Revenue Regret ($/ acre/ annum)	Max Erosion Regret (+) (tons/ acre/ annum)	Max Erosion Regret (-) (tons/ acre/ annum)	Exp Erosion Regret (tons/ acre/ annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/ acre/ annum (%)	Freq of Erosion <1.5 tons/ acre/ annum (%)	Freq of Erosion <1.0 tons/ acre/ annum (%)
1	CS	CT	VT	238	116.4	0.00*	-5.96	-1.72	20	16	10	39	21	4
2	CS	CT	CN	148	66.8	1.01	-3.45	-0.88	32	25	16	85	57	27
3	CSWDCS	CT	CN	191	79.4	1.12	-2.77	-0.82	23	13	8	95	65	29
4	CS	NT	VT	89	24.2	1.95	-1.38	-0.06	72	57	27	100*	99	93
5	CSWDCS	NT	VT	93	30.0	2.08	-0.42	0.01*	69	42	17	100*	100*	100*
6	CCSWMMMM	CT	CN	185	71.2	2.06	-0.62	-0.02	28	17	8	100*	100*	100*
7	CS	NT	CN	80	12.7*	2.18	-0.44	0.12	84*	73*	56*	100*	100*	100*
8	CSWDCS	NT	CN	75*	20.5	2.35	-0.05*	0.16	82	60	43	100*	100*	100*
9	CCSWMMMM	NT	VT	193	67.0	2.25	-0.12	0.16	31	26	17	100*	100*	100*

Table 6.25 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 11 2, LMU 13 1, LMU 14 1, LMU 14 2, and LMU 16 3

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/ acre/ annum)	Exp Revenue Regret ($/ acre/ annum)	Max Erosion Regret (+) (tons/ acre/ annum)	Max Erosion Regret (-) (tons/ acre/ annum)	Exp Erosion Regret (tons/ acre/ annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/ acre/ annum (%)	Freq of Erosion <1.5 tons/ acre/ annum (%)	Freq of Erosion <1.0 tons/ acre/ annum (%)
1	CSWDCS	NT	CN	49	15.3	1.84	-7.43	-1.07	1	1	0	42	25	7
2	CSWDCS	NT	VT	45	11.6	0.85	-15.42	-3.10	5	5	4	7	1	0
3	CS	CT	CN	45	14.2	0.00*	-18.46	-5.45	7	5	1	0	0	0
4	CCSWMMMM	NT	CN	50	18.6	2.33	-2.91	-0.17*	1	1	0	91	68	28
5	CCSWMMMM	CT	CN	48	16.8	2.04	-4.79	-0.85	2	1	1	50	25	8
6	COVER			54	5.40*	2.81	0.00*	0.77	0	0	0	100*	100*	100*
7	CS	NT	CN	49	18.8	1.41	-14.65	-3.18	3	1	0	5	2	1
8	CCSWMMMM	CT	VT	44	12.2	1.25	-10.13	-2.65	15*	12*	12*	8	1	0
9	CS	NT	VT	43*	14	0.24	-29.85	-7.32	4	1	0	1	0	0

Table 6.26 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 1

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/acre/annum)	Exp Revenue Regret ($/acre/annum)	Max Erosion Regret (+) (tons/acre/annum)	Max Erosion Regret (-) (tons/acre/annum)	Exp Erosion Regret (tons/acre/annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/acre/annum (%)	Freq of Erosion <1.5 tons/acre/annum (%)	Freq of Erosion <1.0 tons/acre/annum (%)
1	CSWDCS	NT	CN	77	25.1	1.56	-6.31	-1.52	1	1	0	28	15	4
2	CSWDCS	NT	VT	74	20.0	0.44	-13.21	-3.83	2	2	2	4	1	0
3	CS	NT	VT	79	18.3	0.00*	-29.10	-8.09	11	11	10	0	0	0
4	CCSWMMMM	NT	CN	50*	14.3	2.27	-2.75	-0.33*	24*	24*	24*	93	69	31
5	CCSWMMMM	NT	VT	49	17.9	1.87	-6.09	-1.44	5	4	3	31	14	3
6	CS	NT	CN	82	24.4	1.33	-14.26	-3.65	4	2	1	4	1	0
7	COVER			57	5.6*	2.60	0.00*	0.59	0	0	0	100*	100*	100*
8	CCSWMMMM	CT	CN	52	18.2	2.04	-5.11	-1.13	5	5	4	41	18	8

Table 6.27 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 2

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/ acre/ annum)	Exp Revenue Regret ($/ acre/ annum)	Max Erosion Regret (+) (tons/ acre/ annum)	Max Erosion Regret (-) (tons/ acre/ annum)	Exp Erosion Regret (tons/ acre/ annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/ acre/ annum (%)	Freq of Erosion <1.5 tons/ acre/ annum (%)	Freq of Erosion <1.0 tons/ acre/ annum (%)
1	CSWDCS	CT	VT	164	66.5	0.40	-3.72	-1.02	22	19	14	64	35	14
2	CS	CT	VT	159	79.1	0.00*	-5.34	-1.50	14	10	4	34	18	5
3	CS	CT	CN	134	52.2	0.87	-2.80	-0.69	22	13	8	86	62	25
4	CSWDCS	CT	CN	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
5	CCSWMMMM	CT	VT	144	53.4	1.50	-0.72	-0.03*	12	8	6	100*	99	91
6	CS	NT	VT	123	31.7	1.56	-1.26	-0.04	35	21	14	100*	96	82
7	CSWDCS	NT	VT	57*	8.0*	1.75	-1.25	0.20	87*	81*	59*	100*	99	98
8	CS	NT	CN	126	24.5	1.84	-0.51*	0.19	47	34	30	100*	100*	97
9	CCSWMMMM	CT	CN	145	47.4	1.81	-0.19	0.20	20	15	10	100*	100*	99
10	CSWDCS	NT	CN	59	8.6	2.07	-0.51	0.34	86	79	58	100*	100*	99

Table 6.28 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 2, LMU 14 3, and LMU 15 2

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/ acre/ annum)	Exp Revenue Regret ($/ acre/ annum)	Max Erosion Regret (+) (tons/ acre/ annum)	Max Erosion Regret (-) (tons/ acre/ annum)	Exp Erosion Regret (tons/ acre/ annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/ acre/ annum (%)	Freq of Erosion <1.5 tons/ acre/ annum (%)	Freq of Erosion <1.0 tons/ acre/ annum (%)
1	CSWDCS	CT	CN	90	31.2	1.63	-4.17	-1.23	6	4	4	44	19	8
2	CS	CT	CN	98	25.9	1.31*	-6.32	-1.86	14	9	4	20	8	1
3	CCSWMMMM	CT	VT	83	28.3	1.92	-2.72	-0.69	7	4	3	77	44	16
4	CSWDCS	NT	VT	75	18.4	2.15	-1.19	-0.28	14	7	5	96	82	45
5	CSWDCS	NT	CN	64*	8.6*	2.38	0.00*	0.22	61*	54*	52*	100*	100*	97
6	CCSWMMMM	CT	CN	83	18.9	2.27	-0.76	0.01*	32	30	27	100*	99	78
7	CS	NT	CN	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
8	CCSWMMMM	NT	VT	87	20.5	2.31	-0.51	0.06	31	25	11	100*	99	85

Table 6.29 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 3

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/acre/annum)	Exp Revenue Regret ($/acre/annum)	Max Erosion Regret (+) (tons/acre/annum)	Max Erosion Regret (-) (tons/acre/annum)	Exp Erosion Regret (tons/acre/annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/acre/annum (%)	Freq of Erosion <1.5 tons/acre/annum (%)	Freq of Erosion <1.0 tons/acre/annum (%)
1	CSWDCS	CT	VT	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
2	CS	CT	VT	178	90.9	0.00*	-4.63	-1.29	8	7	5	52	29	10
3	CCSWMMMM	CT	VT	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
4	CSWDCS	CT	CN	192	62.6	1.61	-0.61	-0.02*	11	7	4	100*	100*	97
5	CS	CT	CN	123	53.8	0.59	-2.44	-0.58	15	12	6	92	73	37
6	CS	NT	VT	98	33.4	1.53	-0.75	-0.03	45	33	11	100*	99	90
7	CSWDCS	NT	VT	49*	8.3*	2.09	-0.24	0.18	95*	85	64*	100*	100*	100*
8	CCSWMMMM	CT	CN	101	26.2	1.87	-0.36	0.17	51	44	36	100*	100*	100*
9	CS	NT	CN	195	58.1	2.00	-0.20	0.18	13	9	8	100*	100*	100*
10	CCSWMMMM	NT	VT	53	8.9	2.27	-0.06*	0.29	94	86*	58	100*	100*	100*

Table 6.30 Summary of Regret and Robustness Analyses under the Farm Based Analysis for LMU 15 1

Opt Man Prac *(M)*	Crop Rotation	Till Sys	Mech Contr Prac	Max Revenue Regret ($/ acre/ annum)	Exp Revenue Regret ($/ acre/ annum)	Max Erosion Regret (+) (tons/ acre/ annum)	Max Erosion Regret (-) (tons/ acre/ annum)	Exp Erosion Regret (tons/ acre/ annum)	Freq of Revenue >0.85 * *RVmax* (%)	Freq of Revenue >0.90 * *RVmax* (%)	Freq of Revenue >0.95 * *RVmax* (%)	Freq of Erosion <2.0 tons/ acre/ annum (%)	Freq of Erosion <1.5 tons/ acre/ annum (%)	Freq of Erosion <1.0 tons/ acre/ annum (%)
1	CSWDCS	CT	VT	247	85.5	0.12	-2.10	-0.54	36	28	20	95	86	44
2	CS	CT	VT	235	101.2	0.00*	-2.46	-0.65	30	20	14	92	76	33
3	CCSWMMMM	CT	VT	273	98.9	1.32	-0.40	0.08*	14	7	4	100*	100*	99
4	CSWDCS	CT	CN	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
5	CS	CT	CN	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
6	CS	NT	VT	118	28.0	1.63	-0.20	0.19	75	64	36	100*	100*	100*
7	CSWDCS	NT	VT	95*	18*	1.68	-0.11	0.23	90*	75*	62*	100*	100*	100*
8	CCSWMMMM	CT	CN	276	98.8	1.62	-0.16	0.21	13	6	4	100*	100*	100*
9	CS	NT	CN	121	29.4	1.80	-0.06*	0.28	74	62	30	100*	100*	100*

CHAPTER 7

SUMMARY AND CONCLUSIONS

The study described in this thesis focuses on incorporating uncertainty in the management decisions concerning the control of nonpoint source pollution from agricultural land by controlling erosion and sedimentation. Three critical issues are addressed. They are:

1) the identification of management policies that are robust to uncertainty in the input parameters;
2) the identification of input parameters that are significant for the modelling of erosion and sedimentation, as well as for making effective management decisions; and
3) the identification of management practices that are robust to uncertainty in the input parameters.

Three management policies are analyzed, the Least Cost policy, the Erosion Tax policy, and the Erosion Standard policy. The Least Cost policy must be based on a watershed based analysis. The Erosion Standard policy, on the other hand, requires erosion criteria to be met at the farm level. For the Erosion Tax policy both the entire watershed and the individual farms must be considered.

Three approaches are used to address the issues of uncertainty. Monte Carlo Simulation is used to evaluate the sensitivity of management policies to uncertainty in the input parameters. A Modified Generalized Sensitivity Analysis is used to identify the important parameters in the linked process of water quality simulation and optimization modelling for sediment control. The Regret and Robustness Analyses are used to identify management practices that are likely to be appropriate for future conditions that can be expected to differ from past conditions. The Highland Silver Lake Watershed in Illinois is used as a case study. The SEDEC model is used to obtain the most cost-effective set of management practices by simulation and optimization. Thirty management practices, consisting of combinations of five crop rotations, three tillage systems, and two mechanical erosion control practices, are considered. The SEDEC model is first used with deterministic input data to obtain a basis for comparison with results where uncertainty in the input parameters is taken into account.

7.1 Management Policy and Practices with Deterministic Input Data

The analysis with deterministic input data shows the Least Cost policy to be the most cost-effective management policy for the Highland Silver Lake Watershed. The Erosion Standard policy is the least cost-effective management policy. The latter conclusion, however, is valid only for a sediment limitation greater than 35 tons/annum. For a sediment limitations of 35 tons/annum and less, the Erosion Standard policy performs better than the Erosion Tax policy. This result agrees with the studies by Miltz et al. (1988) and Braden et al. (1989). The deterministic analysis also shows that changes in management practices required to meet the sediment restrictions involve a much smaller area with the Least Cost policy than with the other two policies. This is to be expected since the LMUs that are adjacent to the stream contribute directly to the sediment load while they act as screens for sediment coming from LMUs that are further upslope. Thus measures to prevent erosion and to trap sediment in the LMUs adjacent to the stream go a long way in solving the entire sedimentation problem in this system.

The changes in management practices required to meet sediment limitations depend on the management policies. With the Least Cost policy, the sediment delivery ratio plays an important role in the management decisions. With the Erosion Tax policy, the required changes in management practices depend on the trade-off between erosion rates and erosion abatement costs rather than on the sediment delivery ratio. With the Erosion Standard policy, the required changes in management practices depend on the individual erosion rates. The results from this policy are not sensitive to either the erosion abatement costs or the sediment delivery ratio. The Least Cost policy is a centralized management strategy which allows trade-offs among the LMUs. It is therefore not surprising that the Least Cost policy is the most cost-effective.

7.2 Management Decisions based on Uncertain Input Data

7.2.1 Sensitivity of Management Policies to Uncertainty

Monte Carlo Simulation is used to generate the total cost in terms of the total Relative Revenue Reduction associated with each management alternative for a large number of realizations of the uncertain model input parameters and a given sediment load constraint. The frequency distribution of the total cost figures is then obtained.

The results show that of the three management policies, the Least Cost policy shows a total RRR that has the smallest variance especially for the larger values of total sediment allowed in the stream. The Least Cost policy results are therefore the least sensitive to input uncertainty. The reason is that the Least Cost policy allows centralized decisions in which LMUs can be dealt with according to their actual contribution to the sediment in the stream.

The results also show that for the more severe constraints on the sediment load the difference between the three policies decreases. For a sediment constraint of about 30 tons/annum the performance of all three is about the same. The study also shows that the common assumptions, that the Erosion Tax policy is more cost-effective than the Erosion Standard policy and that the Least Cost policy performs better than either of the other two policies, is not necessarily true for stochastic input parameters.

7.2.2 Modified Generalized Sensitivity Analysis

The Modified Generalized Sensitivity Analysis, which in earlier studies was used to identify the important parameters that should be included in a point source water quality management model, is extended to identify the important parameters in the model used for nonpoint source water quality management. The input parameters examined are: the rainfall erosivity factor R used in the USLE; the crop yield for corn, soybeans, wheat, double-crop-soybeans, and meadow; and the crop prices for corn, soybeans, wheat, and meadow. The results show that the rainfall erosivity factor R and the crop prices for corn and soybeans are consistently significant parameters whether the analysis is based on the entire watershed or on individual farms. The crop price for wheat is to some degree important, while the revenue for pasture is not a significant parameter. The reason that the *R* factor is important is that in the USLE the *R* factor directly affects erosion. This makes it important at the farm level where erosion must be controlled and for the watershed as a whole since the erosion determines the total sediment load on the stream. The importance of the two crop prices is consistent with the fact that corn and soybeans are the most profitable crops in the study area. The yield parameters are not significant for the Watershed based analysis but they are significant for the Farm based analysis, except for areas used for pasture. Crop yield influences not only the revenue of the individual farm but also the erosion because increased yield is associated with more crop residue which plays an important role in reducing erosion. When the watershed as a whole is considered, the Behaviour classification is based on total sediment and total revenue for the entire watershed. Total sediment load is not only a function of erosion but also of the sediment delivery ratio. The yield parameters are not very significant for total sediment delivery. They do affect the revenue from the entire watershed but not nearly as markedly as for individual farms. Although there is no strong indication that slope influences which input parameters are significant, a general trend can be noted. When farm based management is considered, the number of important yield parameters decreases as erosion is more restricted. For a slope gradient greater than 6% and for an erosion limitation of 1 ton/acre, none of the yield parameters is significant. A similar result is found with a tax of $2.00/ton and $11.00/ton. The reason is that as more restrictions are placed on erosion, eventually only two management alternatives may be employed. These are leaving the land covered with grass or alfalfa, which generates no revenue, or using a management alternative with a high cost to maintain the erosion or sediment load criteria. In this case yield is evidently less significant. When the entire watershed is considered, the yield parameters of importance can be reduced from sixty five to only fifteen parameters. It may be concluded that *R* and the price parameters are important for both the watershed and farm scales. Yield parameters may or may not be important depending on the management policy. This means that under the Least Cost policy, the manager may concentrate of managing those LMUs close to the stream, that produce the most sediment. Under the Erosion Standard policy, the manager must base decisions on the erosion concern and the farm revenue in each LMU.

7.2.3 Regret and Robustness Analyses

Regret and Robustness Analyses are used to identify the robust set of management practices for the LMUs. The analyses are performed for the watershed as a whole and for the individual farms. Watershed based analysis is based on the Least Cost policy. Using the total sediment restriction of 262 tons/annum, which corresponds to an allowable farm erosion rate of 3 tons/acre/annum, three robust sets of optimum management practices are found for the entire watershed. These three practices are similar. Trade-offs between CCSWMMMM and COVER, CT and CN, and NT and VT occur especially in the LMUs adjacent to the stream. The choice between these must be left to the decision maker. Farm based analysis assumes the Erosion Standard policy. Using an allowable farm erosion rate of 3 tons/acre/annum, either one or two robust management practices are found for each LMU. The choice among these is left to the decision maker. The two management studies confirm the finding in the Modified Generalized Sensitivity Analysis that yields are important parameters for Farm based analysis but not for the Watershed based analysis. For both cases, optimum crop rotations depend on soil formation and slope gradient. CSWDCS is used as a crop rotation for LMUs with slope gradients under 2%, while CS or CSWDCS is used as a crop rotation for LMUs with slope gradients of 2%. For land with slope gradients greater than 2% and up to 4%, CSWDCS or CCSWMMMM is used. CCSWMMMM or COVER is used for LMUs with land slope of about 6% up to 13%. COVER is used for LMUs with slope gradients of 13% or higher. For both cases, Watershed and Farm based analyses, the robust management alternatives require mostly contour cultivation as the mechanical erosion control practice.

The sets of robust management alternatives are compared with the optimum management alternatives based on the deterministic input data. The difference lies in the tillage system or in the mechanical erosion control practices. With the deterministic input data VT turns out to be adequate as the tillage system and CT can be used as the mechanical erosion control practice. Of the 37 LMUs, only one requires a change from CT to NT, and two require changes from VT to CN. The sets of robust management practices require either NT as the tillage system or CN as the mechanical erosion control practice. The robust management practices therefore result in a smaller sediment load, i.e., in smaller sediment regret.

How robust the chosen management alternatives are is an important question not only for the decision maker but also for the farmers. Providing this information to the farmers may increase their participation in adopting the management practices. This is important since farmer participation is essential to reaching the goal of meeting the environmental criteria at minimum cost.

7.2.4 The Role of Land Slope

The location of the LMUs relative to the stream determines to a large degree their contribution to the total sediment load. Location therefore influences the identification of robust management practices for the Watershed based analysis. It is shown that on this basis the contribution of the sediment from each field to the stream depends on the change in the slope along a transect. A varying slope along the transect results in less sediment to the stream than a uniform slope. A change from a steep slope to a mild slope reduces the sediment flow capacity, and therefore the sediment delivery. Such a change in slope has a more pronounced effect on the sediment delivery if the location is close to the stream. A change from a mild slope to a steep slope may also decrease the sediment delivery to the stream depending on the management practices employed in the steeply sloping land. If the steeper section occurs near the stream then COVER may be used to reduce the erosion.

7.3 Conclusion

This study shows that the Least Cost policy is the management policy that is the least sensitive to uncertain input. The Erosion Tax and Erosion Standard policies are more sensitive. However, for very severe sediment constraints, the three policies are not much different in that the cost of meeting the sediment constraints may be very similar for all three policies.

For Watershed based analysis, three robust sets of management practices are identified using the Regret and Robustness Analysis. The differences between the three sets are not great and the choice is a matter of preference of the decision maker. The robust set chosen is not necessarily the optimum for a given set of input data but comes close to minimizing both revenue regret and sediment regret for stochastic input data. For Farm based analysis, robust management practices are identified for each of the 37 LMUs. In several cases, more than one management alternative is acceptable. The choice among these is left to the decision maker.

Input parameters that are important for the model are identified with the Modified Generalized Sensitivity Analysis. It is found that the rainfall erosivity factor, *R*, and the prices of corn and soybeans are important parameters in the SEDEC model. The importance of the crop yield parameters depends on the management policy. For the Least Cost policy, crop yields do not influence the results significantly. For the Erosion Standard policy crop yields are important parameters. This means that under the Least Cost policy, the manager may concentrate on managing those LMUs close to the stream, which produces the most sediment. Under the Erosion Standard policy, the manager must base the management decision on the erosion concern and the farm revenue in each LMU.

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NOTATION

a = calibrated watershed parameters
A = annual soil erosion loss [tons/ha]
A_{ij} = soil erosion per area on the jth LMU in Transect i [tons/ha].
AR = watershed area [km^2]
AV_{vT} = annual value of net return for management practices v over T years [\$/ha]
BC_t = budgeted total cost relative to the maximum revenue case in year t for a given soil loss [\$/ton]
BC_{vt} = budgeted cost for management practice v in year t
BR = bifurcation ratio, the ratio of number of streams of any given order to the number in the next-higher order
C = cropping and management factor which is determined by the crop rotation and the tillage system
C_{j-1} = cropping and management factor in the USLE for the jth-1 land segment
C_{ij-1} = cropping and management factor in the USLE for the jth-1 LMU in Transect i
$CCSWMMMM$ = crop rotation corn-corn-soybeans-wheat-meadow-meadow-meadow-meadow
CN = contour cultivation
CS = crop rotation corn-soybeans
$CSWDCSB$ = crop rotation corn-soybeans-wheat-doublecrop-soybeans
$CSWM$ = crop rotation corn-soybeans-wheat-meadow
CT = conventional tillage
$COVER$ = continuous cover (grass or alfafa)
d_{mn}^{x} = the K-S test for parameter X with n number of the Non-Behaviours and m number of the Behaviours
d_{mn}^{x} = maximum distance between the CDFs
d_{mn}^{α} = the theoretical d_{mn} at significant level α
DC = detachment capacity of flow [g/s-m^2]
DF = overland flow detachment rate [kg/min]
DL_{i} = interill detachment rate [g/s-m^2]
DL_r = rill detachment rate [g/s-m^2]
DP_t = cummulative depth of top soil loss up to and including year t [length]
DR = rainfall detachment rate [kg/min]
DT = detachment or deposition by flow [g/s-m^2]
EI = rainfall erosivity factor [MJ-mm/ha-hour]
F_Z = standardized frequency factor, which is a function of the recurrence interval and the type of distribution
FP = fall plowing tillage
h = denotes the soil formation
Hs = seasonal hydrologic coefficient
IT = number of Transects in the watershed
j = upland segment
$j-1$ = low-land segment
k = transport capacity factor
K = soil erodibility factor [ton-ha-hour/ha-MJ-mm]
Ls = seasonal overland flow path
LS = length and steepness of slope factor
LX = distance of the field edge from the stream edge [length]
m = number of items in the Behaviours category
n = number of items in the Non-Behaviours category

ns = seasonal surface roughness
N_{pi} = binary number for selected management sequence in Transect *i*, N_{pi} is equal to 1 if the management sequence is selected, N_{pi} is equal to 0 otherwise
NP = number of dominant management sequences in Transect *i*
NT = no-till
P = conservation practices factor which is determined by the mechanical control practices such as strip cropping and terracing
P_{ij-1} = conservation practices factor in the USLE for the *j*th-*1* LMU in Transect *i*
P_{j-1} = conservation practices factor in the USLE for the *j*th-*1* land segment
$PVNR_{vT}$ = present value of net return for management practice *v* over *T* years [\$/ha]
PR_c = price of the *c*th crop
q = overland flow [m3/s]
q_s = sediment load of flow [g/s-m]
Q = overland flow rate [m^3/min-m]
r = interest rate [%]
R = rainfall-runoff factor or the annual rainfall erosivity factor [MJ-mm/ha-hour]
RE/L = relief length ratio, the ratio of elevation difference between watershed divide and outlet to watershed length
RI = rainfall intensity [mm/min]
RRR = relative revenue reduction
RV_{max}^{I} = maximum revenue for Input Scenario *I* [\$/annum]
RV_{MD}^{I} = revenue using sets of management practices *MD* under Input Scenario *I* [\$/annum]
RGr_{MD}^{I} = revenue regret using sets of management practices *MD* for Input Scenario *I* [\$/annum]
RGs_{MD}^{I} = sediment regret using sets of management practices *MD* for Input Scenario *I* [ton/annum]
si = sine of the slope angle
s^x = the sensitivity index for parameter *x*
S_{j-1} = slope of the *j*th-*1* land segment
S_{ij-1} = slope of the *j*th-*1* LMU in Transect *i*
S = slope steepness
S_{max}^{I} = sediment corresponding to RV_{max}^{I} [ton/annum]
$SA_m(X)$ = sample CDFs for the Behaviour category of parameter *X*
$SA_n(X)$ = sample CDFs for the Non-Behaviour categories of parameter
SDR = sediment delivery ratio [%]
SDR_{j-1} = sediment delivery ratio for land segment *j-1*
SDR_{ij} = sediment transport capacity for the *j*th LMU in Transect *i*
SL_{max} = maximum allowable sediment load in the stream [ton]
S_{MD}^{I} = sediment using sets of management practices *MD* for Input Scenario *I* [ton/annum]
T_c = transport capacity of flow [g/s-m]
T_F = sediment transport capacity [kg/min-m]
TE_{kt} = total erosion from source area *k* in day *t* [Mg]
$TRRR$ = total Relative Revenue Reduction for the entire watershed [\$]
TS_{pi} = total sediment yield using management sequence *p* in Transect *i* [ton]
U_c = average channel velocity [m/s]
U_{ss} = particle fall velocity [m/s]
V_u = runoff volume [m^3/m^2]

VT = vertical cultivation
X = given parameter
Y = sediment yield [tons]
Y_t = yield for a crop in a given year t
Y_{cvt} = yield for the cth crop for management practice v in year t
Z = value of variable Z
ZE_{ij} = proportion of erosion that reach the stream from LMU i in Transect j
α = significant level
β = coefficient ranging from 1.2 to 1.5 in Equation 2.9
γ = percentage of maximum revenue in the Robustness Analysis
δ = percentage of maximum sediment or maximum erosion in the Robustness Analysis
τ = flow shear stress [kg/m^2]
η = effective transport factor
μ_Z = mean value of variable Z
σ_Z = standard deviation of variable Z
σ_p = peak runoff rate [m^3/s-m^2]
ζ = slope length exponent for rill erosion

APPENDIX

Table A.1 Results of Regret and Robustness Analyses under the Watershed Based Analysis

Input Scenario *(I)*	Sets of Management Practices *(MD)*	Maximum Revenue Regret ($/ annum)	Expected Revenue Regret ($/ annum)	Maximum Sediment Regret (+) (tons/ annum)	Maximum Sediment Regret (-) (tons/ annum)	Expected Sediment Regret (tons/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Sediment <200 tons/ annum (%)	Frequency of Sediment <150 tons/ annum (%)	Frequency of Sediment <100 tons/ annum (%)
1	*1*	12025	7135	96	-302	-102.9	14	9	4	35	15	5
2	*2*	13427	8101	49	-680	-236.1	6	4	3	10	2	0
3	*3*	13310	7613	50	-532	-201.6	10	6	4	13	5	0
4	*4*	10223	6417	0	-918	-384.3	14	5	2	1	0	0
5	*5*	10921	6163	164	-118	-15.9	17	8	1	88	60	23
6	*6*	12996	6050	120	-228	-70.0	10	2	1	52	23	9
7	*7*	6039	2046	183	-50	12.2	75	53	27	95	85	41
8	*8*	8002	3364	77	-372	-128.4	41	32	13	26	11	1
9	*9*	7130	3528	159	-94	-18.5	45	34	14	86	59	21
10	*10*	7974	3871	135	-167	-55.3	41	19	9	57	34	12
11	*11*	12790	7981	135	-180	-52.1	8	6	1	65	32	12
12	*12*	10995	6002	90	-342	-111.1	10	5	1	30	13	5
13	*13*	12931	7605	0	-948	-382.1	14	10	4	1	0	0
14	*14*	10128	7023	123	-207	-66.7	9	8	1	55	26	9
15	*15*	7047	2386	166	-81	-9.7	65	43	22	90	65	25
16	*16*	9142	4900	82	-340	-116.8	22	11	1	27	13	3
17	*17*	8298	3326	153	-124	-28.9	44	25	8	76	49	16
18	*18*	8060	3532	153	-114	-23.5	46	28	11	82	56	19
19	*19*	6898	2317	205	0	39.7	70	48	17	100	97	80
20	*20*	8296	2947	185	-46	12.3	57	35	16	96	85	46

Table A.1 Results of Regret and Robustness Analyses under the Watershed Based Analysis (Continued)

Input Scenario *(I)*	Sets of Management Practices *(MD)*	Maximum Revenue Regret ($/ annum)	Expected Revenue Regret ($/ annum)	Maximum Sediment Regret (+) (tons/ annum)	Maximum Sediment Regret (-) (tons/ annum)	Expected Sediment Regret (tons/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Sediment <200 tons/ annum (%)	Frequency of Sediment <150 tons/ annum (%)	Frequency of Sediment <100 tons/ annum (%)
21	*21*	12311	7309	121	-245	-75.5	11	10	4	48	25	10
22	*22*	12454	7370	123	-238	-73.8	14	7	3	50	25	10
23	*23*	10350	5842	128	-180	-53.9	22	11	6	65	33	11
24	*24*	11338	5936	47	-630	-231.5	20	10	6	10	2	0
25	*25*	9698	4849	64	-487	-176.0	32	17	8	14	8	1
26	*26*	8267	3939	77	-396	-137.1	44	29	12	24	11	1
27	*27*	7390	4430	80	-393	-130.4	37	19	4	26	12	1
28	*28*	8248	4644	168	-68	-7.1	32	18	6	91	69	28
29	*29*	9534	4567	94	-326	-109.1	31	12	7	32	15	3
30	*30*	9366	4820	154	-115	-23.7	29	18	5	82	55	17
31	*31*	9366	4820	154	-115	-23.7	29	18	5	82	55	17
32	*32*	12075	7249	65	-492	-176.5	14	9	4	14	8	1
33	*33*	11984	6730	83	-367	-127.0	23	13	2	25	13	1
34	*34*	12627	7103	70	-564	-195.3	13	9	3	13	6	1
35	*35*	12888	7427	72	-443	-158.9	18	10	3	17	9	1
36	*36*	10327	5806	58	-532	-190.1	21	9	1	13	6	1
37	*37*	9886	5320	72	-464	-160.8	27	13	4	19	10	1
38	*38*	9460	5191	111	-287	-86.7	29	12	1	44	21	7
39	*39*	6952	3745	74	-383	-138.1	42	28	15	23	11	1
40	*40*	7598	3348	113	-249	-83.9	45	20	1	41	23	7

Table A.1 Results of Regret and Robustness Analyses under the Watershed Based Analysis (Continued)

Input Scenario *(I)*	Sets of Management Practices *(MD)*	Maximum Revenue Regret ($/ annum)	Expected Revenue Regret ($/ annum)	Maximum Sediment Regret (+) (tons/ annum)	Maximum Sediment Regret (-) (tons/ annum)	Expected Sediment Regret (tons/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Sediment <200 tons/ annum (%)	Frequency of Sediment <150 tons/ annum (%)	Frequency of Sediment <100 tons/ annum (%)
41	*41*	11072	6634	117	-268	-79.1	13	6	3	43	22	8
42	*42*	11754	6894	127	-200	-61.5	22	9	1	57	26	9
43	*43*	11146	6792	99	-328	-107.3	20	9	3	35	16	3
44	*44*	10245	5251	116	-234	-75.2	32	16	6	47	25	9
45	*45*	9785	5255	76	-393	-141.7	26	17	5	21	11	1
46	*46*	9512	4726	97	-293	-93.0	31	16	4	38	17	6
47	*47*	9476	4358	87	-319	-110.5	33	17	7	28	14	4
48	*48*	9297	4883	106	-275	-91.4	28	11	1	40	19	7
49	*49*	8297	3894	180	-53	8.8	39	25	5	97	84	40
50	*50*	8005	2290	164	-78	-11.0	72	58	25	88	65	26
51	*51*	10628	6258	71	-505	-197.2	15	5	1	13	5	1
52	*52*	14137	8375	54	-621	-217.7	5	4	3	10	3	1
53	*53*	12796	7728	138	-176	-48.7	6	3	1	66	33	12
54	*54*	10396	5298	124	-219	-74.0	30	9	4	48	25	9
55	*55*	10674	5368	31	-744	-275.9	20	10	3	8	1	0
56	*56*	9740	4855	3	-989	-381.2	33	14	7	1	0	0
57	*57*	8217	4756	143	-143	-40.9	36	21	7	71	38	13
58	*58*	9078	5038	59	-508	-188.4	23	11	3	14	7	1
59	*59*	9341	4301	84	-370	-120.2	34	19	8	28	14	2
60	*60*	8955	4496	157	-117	-20.5	23	16	2	84	56	22

Table A.1 Results of Regret and Robustness Analyses under the Watershed Based Analysis (Continued)

Input Scenario *(I)*	Sets of Management Practices *(MD)*	Maximum Revenue Regret ($/ annum)	Expected Revenue Regret ($/ annum)	Maximum Sediment Regret (+) (tons/ annum)	Maximum Sediment Regret (-) (tons/ annum)	Expected Sediment Regret (tons/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Sediment <200 tons/ annum (%)	Frequency of Sediment <150 tons/ annum (%)	Frequency of Sediment <100 tons/ annum (%)
61	*61*	12135	7596	141	-177	-44.8	11	5	3	67	38	13
62	*62*	11826	7434	29	-754	-285.3	12	8	3	7	1	0
63	*63*	11878	6941	94	-299	-109.7	8	6	3	31	15	2
64	*64*	11595	7071	137	-168	-43.7	10	2	1	69	38	12
65	*65*	9396	4308	184	-63	13.0	36	17	7	95	87	49
66	*66*	7827	3514	119	-262	-77.6	43	22	7	46	25	9
67	*67*	8015	4179	141	-143	-40.3	34	18	4	70	38	13
68	*68*	11904	6900	98	-337	-109.2	14	9	4	34	16	3
69	*69*	6045	2821	180	-52	9.2	54	41	25	95	82	40
70	*70*	8108	785	191	-24	22.3	95	89	74	97	93	60
71	*71*	11655	7166	41	-669	-248.6	15	9	4	9	1	0
72	*72*	9741	5603	153	-114	-26.9	12	8	3	82	53	16
73	*73*	13573	7986	14	-895	-332.8	9	5	3	3	1	0
74	*74*	12872	7811	67	-481	-170.6	9	7	3	16	9	1
75	*75*	14547	5499	176	-56	4.8	21	12	6	95	77	37
76	*76*	10900	5167	80	-399	-130.0	25	10	5	25	12	1
77	*77*	10587	5852	89	-361	-118.1	13	6	1	28	14	2
78	*78*	8852	4276	78	-379	-132.1	35	14	5	24	11	1
79	*79*	8966	4190	169	-72	-6.8	38	22	6	90	67	28
80	*80*	10917	3512	191	-27	23.2	46	22	8	97	94	59

Table A.1 Results of Regret and Robustness Analyses under the Watershed Based Analysis (Continued)

Input Scenario *(I)*	Sets of Management Practices *(MD)*	Maximum Revenue Regret ($/ annum)	Expected Revenue Regret ($/ annum)	Maximum Sediment Regret (+) (tons/ annum)	Maximum Sediment Regret (-) (tons/ annum)	Expected Sediment Regret (tons/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Sediment <200 tons/ annum (%)	Frequency of Sediment <150 tons/ annum (%)	Frequency of Sediment <100 tons/ annum (%)
81	*81*	11637	7029	83	-348	-121.8	11	8	3	27	13	2
82	*82*	11206	7232	118	-218	-73.1	15	9	2	50	25	9
83	*83*	14048	7999	77	-466	-157.0	9	4	3	21	9	1
84	*84*	11599	6282	69	-407	-141.1	23	12	5	22	10	1
85	*85*	11238	6314	73	-442	-153.1	13	7	1	20	9	1
86	*86*	11517	6547	98	-343	-108.7	11	5	1	34	14	4
87	*87*	9866	4899	81	-334	-117.5	22	12	4	27	13	3
88	*88*	10190	5141	78	-381	-135.1	21	11	5	24	11	2
89	*89*	7658	3347	178	-48	5.7	44	30	12	95	78	37
90	*90*	7319	4045	74	-387	-138.2	42	26	8	22	11	1
91	*91*	11248	6850	108	-284	-96.3	22	12	3	39	19	5
92	*92*	12297	7488	73	-417	-152.9	15	10	3	20	9	1
93	*93*	12307	7270	108	-282	-91.6	15	10	3	39	18	7
94	*94*	12192	6946	86	-350	-119.9	20	11	5	28	12	3
95	*95*	11558	6734	125	-210	-64.2	22	11	3	57	27	10
96	*96*	8339	4687	177	-60	6.4	27	13	2	95	80	37
97	*97*	7823	3775	150	-126	-30.0	41	27	6	76	50	16
98	*98*	6575	3581	161	-97	-15.0	46	26	10	88	61	24
99	*99*	9182	4582	66	-421	-175.0	26	6	2	14	8	1
100	*100*	8055	3927	103	-299	-96.5	35	14	3	38	18	6

Table A.2 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 1 2, LMU 3 2, LMU 9 3, and LMU 16 2

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
1	*1*	82	29.1	1.74	-1.72	-0.34	22	17	7	92	73	36
2	*2*	131	68.6	0.28	-8.96	-2.47	6	5	3	11	3	0
3	*3*	124	68.7	0.69	-5.29	-1.67	11	11	8	28	11	1
4	*3*	124	68.7	0.69	-5.29	-1.67	11	11	8	28	11	1
5	*4*	153	86.6	0.00	-11.88	-4.06	6	5	5	1	1	0
6	*1*	82	29.1	1.74	-1.72	-0.34	22	17	7	92	73	36
7	*5*	101	31.6	1.86	-1.20	-0.15	34	30	20	98	90	54
8	*3*	124	68.7	0.69	-5.29	-1.67	11	11	8	28	11	1
9	*6*	124	63.4	1.17	-3.71	-1.02	9	8	4	54	28	10
10	*1*	82	29.1	1.74	-1.72	-0.34	22	17	7	92	73	36
11	*1*	82	29.1	1.74	-1.72	-0.34	22	17	7	92	73	36
12	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
13	*1*	82	29.1	1.74	-1.72	-0.34	22	17	7	92	73	36
14	*1*	82	29.1	1.74	-1.72	-0.34	22	17	7	92	73	36
15	*5*	101	31.6	1.86	-1.20	-0.15	34	30	20	98	90	54
16	*8*	91	33.7	1.82	-2.07	-0.25	20	12	7	94	78	51
17	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
18	*5*	101	31.6	1.86	-1.20	-0.15	34	30	20	98	90	54
19	*5*	101	31.6	1.86	-1.20	-0.15	34	30	20	98	90	54
20	*5*	101	31.6	1.86	-1.20	-0.15	34	30	20	98	90	54

Table A.2 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 1 2, LMU 3 2, LMU 9 3, and LMU 16 2 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
21	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
22	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
23	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
24	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
25	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
26	*5*	101	31.6	1.86	-1.20	-0.15	34	30	20	98	90	54
27	*5*	101	31.6	1.86	-1.20	-0.15	34	30	20	98	90	54
28	*5*	101	31.6	1.86	-1.20	-0.15	34	30	20	98	90	54
29	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
30	*5*	101	31.6	1.86	-1.20	-0.15	34	30	20	98	90	54
31	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
32	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
33	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
34	*8*	91	33.7	1.82	-2.07	-0.25	20	12	7	94	78	51
35	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
36	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
37	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
38	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
39	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
40	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92

Table A.2 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 1 2, LMU 3 2, LMU 9 3, and LMU 16 2 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
41	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
42	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
43	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
44	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
45	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
46	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
47	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
48	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
49	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
50	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
51	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
52	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
53	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
54	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
55	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
56	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
57	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
58	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
59	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
60	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92

Table A.2 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 1 2, LMU 3 2, LMU 9 3, and LMU 16 2 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
61	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
62	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
63	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
64	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
65	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
66	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
67	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
68	*8*	91	33.7	1.82	-2.07	-0.25	20	12	7	94	78	51
69	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
70	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
71	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
72	*8*	91	33.7	1.82	-2.07	-0.25	20	12	7	94	78	51
73	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
74	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
75	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
76	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
77	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
78	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
79	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
80	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92

Table A.2 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 1 2, LMU 3 2, LMU 9 3, and LMU 16 2 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
81	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
82	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
83	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
84	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
85	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
86	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
87	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
88	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
89	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
90	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
91	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
92	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
93	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
94	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
95	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
96	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
97	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
98	*9*	101	30.6	1.97	-0.75	-0.02	36	31	24	98	95	69
99	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92
100	*7*	77	7.1	2.14	-0.58	0.19	82	76	71	100	99	92

Table A.3 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 2 1, LMU 5 2, LMU 6 2, LMU 7 1, LMU 8 1, and LMU 9 1

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
1	*1*	131	63.6	0.32	-3.48	-1.10	13	9	5	75	50	14
2	*2*	151	74.7	0.00	-3.65	-1.50	10	7	3	55	25	10
3	*2*	151	74.7	0.00	-3.65	-1.50	10	7	3	55	25	10
4	*3*	118	53.4	1.10	-0.95	-0.23	15	7	3	100	100	94
5	*3*	118	53.4	1.10	-0.95	-0.23	15	7	3	100	100	94
6	*4*	120	48.8	0.56	-1.98	-0.79	18	12	5	90	77	33
7	*5*	77	35.1	0.75	-1.92	-0.55	26	14	11	98	90	61
8	*5*	77	35.1	0.75	-1.92	-0.55	26	14	11	98	90	61
9	*5*	77	35.1	0.75	-1.92	-0.55	26	14	11	98	90	61
10	*3*	118	53.4	1.10	-0.95	-0.23	15	7	3	100	100	94
11	*6*	105	31.8	1.17	-1.06	-0.21	37	27	7	100	99	92
12	*7*	68	11.5	1.38	-0.34	-0.01	88	76	22	100	100	100
13	*7*	68	11.5	1.38	-0.34	-0.01	88	76	22	100	100	100
14	*7*	68	11.5	1.38	-0.34	-0.01	88	76	22	100	100	100
15	*7*	68	11.5	1.38	-0.34	-0.01	88	76	22	100	100	100
16	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
17	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
18	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
19	*7*	68	11.5	1.38	-0.34	-0.01	88	76	22	100	100	100
20	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100

Table A.3 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 2 1, LMU 5 2, LMU 6 2, LMU 7 1, LMU 8 1, and LMU 9 1 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
21	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
22	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
23	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
24	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
25	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
26	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
27	*10*	105	43.7	1.63	-0.06	0.09	24	19	14	100	100	100
28	*10*	105	43.7	1.63	-0.06	0.09	24	19	14	100	100	100
29	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
30	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
31	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
32	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
33	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
34	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
35	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
36	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
37	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
38	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
39	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
40	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100

Table A.3 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 2 1, LMU 5 2, LMU 6 2, LMU 7 1, LMU 8 1, and LMU 9 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
41	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
42	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
43	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
44	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
45	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
46	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
47	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
48	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
49	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
50	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
51	*10*	105	43.7	1.63	-0.06	0.09	24	19	14	100	100	100
52	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
53	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
54	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
55	*10*	105	43.7	1.63	-0.06	0.09	24	19	14	100	100	100
56	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
57	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
58	*10*	105	43.7	1.63	-0.06	0.09	24	19	14	100	100	100
59	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
60	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100

Table A.3 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 2 1, LMU 5 2, LMU 6 2, LMU 7 1, LMU 8 1, and LMU 9 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
61	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
62	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
63	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
64	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
65	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
66	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
67	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
68	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
69	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
70	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
71	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
72	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
73	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
74	*10*	105	43.7	1.63	-0.06	0.09	24	19	14	100	100	100
75	*10*	105	43.7	1.63	-0.06	0.09	24	19	14	100	100	100
76	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
77	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
78	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
79	*10*	105	43.7	1.63	-0.06	0.09	24	19	14	100	100	100
80	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100

Table A.3 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 2 1, LMU 5 2, LMU 6 2, LMU 7 1, LMU 8 1, and LMU 9 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
81	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
82	*10*	105	43.7	1.63	-0.06	0.09	24	19	14	100	100	100
83	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
84	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
85	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
86	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
87	*10*	105	43.7	1.63	-0.06	0.09	24	19	14	100	100	100
88	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
89	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
90	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
91	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
92	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
93	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
94	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
95	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
96	*8*	108	24.8	1.39	-0.52	-0.02	49	39	29	100	100	100
97	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
98	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
99	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100
100	*9*	71	5.3	1.59	-0.04	0.10	93	84	74	100	100	100

Table A.4 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 4 1, LMU 5 1, and LMU 6 1

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
1	*1*	245	84.9	0.24	-4.35	-1.29	13	9	6	63	35	10
2	*2*	201	89.5	0.00	-5.31	-1.64	11	10	5	46	20	7
3	*1*	245	84.9	0.24	-4.35	-1.29	13	9	6	63	35	10
4	*1*	245	84.9	0.24	-4.35	-1.29	13	9	6	63	35	10
5	*3*	145	56.2	0.55	-2.81	-0.86	20	13	9	87	68	29
6	*4*	160	59.2	1.15	-0.93	-0.26	15	11	7	100	99	91
7	*5*	155	47.0	0.72	-2.23	-0.65	27	17	8	97	82	45
8	*3*	145	56.2	0.55	-2.81	-0.86	20	13	9	87	68	29
9	*3*	145	56.2	0.55	-2.81	-0.86	20	13	9	87	68	29
10	*5*	155	47.0	0.72	-2.23	-0.65	27	17	8	97	82	45
11	*4*	160	59.2	1.15	-0.93	-0.26	15	11	7	100	99	91
12	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
13	*7*	75	16.8	1.42	-0.39	-0.03	80	66	22	100	100	99
14	*8*	102	29.6	1.26	-1.99	-0.19	50	32	11	99	98	94
15	*8*	102	29.6	1.26	-1.99	-0.19	50	32	11	99	98	94
16	*9*	143	50.0	1.41	-0.31	-0.03	29	21	15	100	100	99
17	*7*	75	16.8	1.42	-0.39	-0.03	80	66	22	100	100	99
18	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
19	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
20	*7*	75	16.8	1.42	-0.39	-0.03	80	66	22	100	100	99

Table A.4 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 4 1, LMU 5 1, and LMU 6 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
21	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
22	6	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
23	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
24	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
25	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
26	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
27	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
28	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
29	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
30	6	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
31	6	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
32	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
33	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
34	6	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
35	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
36	11	138	47.6	1.74	-0.05	0.11	29	25	16	100	100	100
37	6	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
38	11	138	47.6	1.74	-0.05	0.11	29	25	16	100	100	100
39	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
40	10	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100

Table A.4 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 4 1, LMU 5 1, and LMU 6 1 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
41	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
42	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
43	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
44	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
45	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
46	*11*	138	47.6	1.74	-0.05	0.11	29	25	16	100	100	100
47	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
48	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
49	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
50	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
51	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
52	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
53	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
54	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
55	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
56	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
57	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
58	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
59	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
60	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100

Table A.4 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 4 1, LMU 5 1, and LMU 6 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
61	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
62	*11*	138	47.6	1.74	-0.05	0.11	29	25	16	100	100	100
63	*11*	138	47.6	1.74	-0.05	0.11	29	25	16	100	100	100
64	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
65	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
66	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
67	*11*	138	47.6	1.74	-0.05	0.11	29	25	16	100	100	100
68	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
69	*1*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
70	*10*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
71	*6*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
72	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
73	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
74	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
75	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
76	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
77	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
78	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
79	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
80	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100

Table A.4 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 4 1, LMU 5 1, and LMU 6 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
81	*11*	138	47.6	1.74	-0.05	0.11	29	25	16	100	100	100
82	*11*	138	47.6	1.74	-0.05	0.11	29	25	16	100	100	100
83	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
84	*11*	138	47.6	1.74	-0.05	0.11	29	25	16	100	100	100
85	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
86	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
87	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
88	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
89	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
90	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
91	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
92	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
93	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
94	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
95	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99
96	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
97	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
98	*11*	138	47.6	1.74	-0.05	0.11	29	25	16	100	100	100
99	*10*	70	9.4	1.73	-0.07	0.10	86	78	63	100	100	100
100	*6*	93	20.8	1.54	-0.99	0.01	64	46	37	100	100	99

Table A.5 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 8 3

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
1	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
2	*2*	77	29.2	1.31	-12.01	-2.91	7	5	3	10	3	1
3	*3*	78	32.9	1.66	-6.23	-1.29	7	6	5	26	13	3
4	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
5	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
6	*3*	78	32.9	1.66	-6.23	-1.29	7	6	5	26	13	3
7	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
8	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
9	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
10	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
11	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
12	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
13	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
14	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
15	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
16	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
17	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
18	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
19	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
20	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30

Table A.5 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 8 3 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
21	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
22	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
23	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
24	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
25	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
26	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
27	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
28	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
29	*2*	77	29.2	1.31	-12.01	-2.91	7	5	3	10	3	1
30	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
31	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
32	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
33	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
34	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
35	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
36	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
37	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
38	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
39	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
40	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30

Table A.5 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 8 3 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
41	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
42	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
43	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
44	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
45	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
46	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
47	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
48	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
49	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
50	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
51	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
52	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
53	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
54	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
55	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
56	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
57	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
58	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
59	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
60	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100

Table A.5 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 8 3 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
61	*1*	70	24.5	1.82	-8.08	-1.01	26	23	21	40	17	7
62	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
63	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
64	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
65	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
66	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
67	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
68	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
69	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
70	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
71	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
72	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
73	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
74	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
75	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
76	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
77	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30
78	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
79	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
80	*5*	61	14.2	2.18	-2.71	-0.07	31	31	31	93	72	30

Table A.5 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 8 3 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
81	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
82	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
83	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
84	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
85	*2*	77	29.2	1.31	-12.01	-2.91	7	5	3	10	3	1
86	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
87	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
88	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
89	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
90	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
91	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
92	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
93	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
94	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
95	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
96	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
97	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
98	*4*	129	19.6	2.56	0.00	0.77	1	1	1	100	100	100
99	*2*	77	29.2	1.31	-12.01	-2.91	7	5	3	10	3	1
100	*5*	61	14.2	2.18	-2.71	-0.07	93	72	30	93	72	30

Table A.6 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 11 1

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
1	*1*	238	116.4	0.00	-5.96	-1.72	20	16	10	39	21	4
2	*1*	238	116.4	0.00	-5.96	-1.72	20	16	10	39	21	4
3	*1*	238	116.4	0.00	-5.96	-1.72	20	16	10	39	21	4
4	*1*	238	116.4	0.00	-5.96	-1.72	20	16	10	39	21	4
5	*1*	238	116.4	0.00	-5.96	-1.72	20	16	10	39	21	4
6	*1*	238	116.4	0.00	-5.96	-1.72	20	16	10	39	21	4
7	*2*	148	66.8	1.01	-3.45	-0.88	32	25	16	85	57	27
8	*2*	148	66.8	1.01	-3.45	-0.88	32	25	16	85	57	27
9	*2*	148	66.8	1.01	-3.45	-0.88	32	25	16	85	57	27
10	*2*	148	66.8	1.01	-3.45	-0.88	32	25	16	85	57	27
11	*3*	191	79.4	1.12	-2.77	-0.82	23	13	8	95	65	29
12	*2*	148	66.8	1.01	-3.45	-0.88	32	25	16	85	57	27
13	*2*	148	66.8	1.01	-3.45	-0.88	32	25	16	85	57	27
14	*2*	148	66.8	1.01	-3.45	-0.88	32	25	16	85	57	27
15	*2*	148	66.8	1.01	-3.45	-0.88	32	25	16	85	57	27
16	*4*	89	24.2	1.95	-1.38	-0.06	72	57	27	100	99	93
17	*5*	93	30.0	2.08	-0.42	0.01	69	42	17	100	100	100
18	*6*	185	71.2	2.06	-0.62	-0.02	28	17	8	100	100	100
19	*5*	93	30.0	2.08	-0.42	0.01	69	42	17	100	100	100
20	*4*	89	24.2	1.95	-1.38	-0.06	72	57	27	100	99	93

Table A.6 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 11 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
21	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
22	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
23	*6*	185	71.2	2.06	-0.62	-0.02	28	17	8	100	100	100
24	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
25	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
26	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
27	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
28	*5*	93	30.0	2.08	-0.42	0.01	69	42	17	100	100	100
29	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
30	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
31	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
32	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
33	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
34	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
35	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
36	*6*	185	71.2	2.06	-0.62	-0.02	28	17	8	100	100	100
37	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
38	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
39	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
40	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100

Table A.6 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 11 1 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
41	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
42	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
43	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
44	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
45	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
46	*9*	193	67.0	2.25	-0.12	0.16	31	26	17	100	100	100
47	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
48	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
49	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
50	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
51	*9*	193	67.0	2.25	-0.12	0.16	31	26	17	100	100	100
52	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
53	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
54	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
55	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
56	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
57	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
58	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
59	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
60	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100

Table A.6 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 11 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
61	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
62	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
63	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
64	*9*	193	67.0	2.25	-0.12	0.16	31	26	17	100	100	100
65	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
66	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
67	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
68	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
69	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
70	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
71	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
72	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
73	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
74	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
75	*9*	193	67.0	2.25	-0.12	0.16	31	26	17	100	100	100
76	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
77	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
78	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
79	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
80	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100

Table A.6 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 11 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
81	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
82	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
83	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
84	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
85	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
86	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
87	*9*	193	67.0	2.25	-0.12	0.16	31	26	17	100	100	100
88	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
89	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
90	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
91	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
92	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
93	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
94	*8*	75	20.5	2.35	-0.05	0.16	82	60	43	100	100	100
95	*9*	193	67.0	2.25	-0.12	0.16	31	26	17	100	100	100
96	*9*	193	67.0	2.25	-0.12	0.16	31	26	17	100	100	100
97	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
98	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100
99	*9*	193	67.0	2.25	-0.12	0.16	31	26	17	100	100	100
100	*7*	80	12.7	2.18	-0.44	0.12	84	73	56	100	100	100

Table A.7 Results of Regret and Robustness Analyses under the Farm Basis Analysis for LMU 11 2, LMU 13 1, LMU 14 1, LMU 14 2, and LMU 16 3

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
1	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	42	25	7
2	*2*	45	11.6	0.85	-15.42	-3.10	5	5	4	7	1	0
3	*2*	45	11.6	0.85	-15.42	-3.10	5	5	4	7	1	0
4	*3*	45	14.2	0.00	-18.46	-5.45	7	5	1	0	0	0
5	*4*	50	18.6	2.33	-2.91	-0.17	1	1	1	91	68	28
6	*5*	48	16.8	2.04	-4.79	-0.85	2	1	1	50	25	8
7	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
8	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	42	25	7
9	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
10	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
11	*5*	48	16.8	2.04	-4.79	-0.85	2	1	1	50	25	8
12	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	42	25	7
13	*7*	49	18.8	1.41	-14.65	-3.18	3	1	1	5	2	1
14	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
15	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
16	*5*	48	16.8	2.04	-4.79	-0.85	2	1	1	50	25	8
17	*4*	50	18.6	2.33	-2.91	-0.17	1	1	1	91	68	28
18	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
19	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
20	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100

Table A.7 Results of Regret and Robustness Analyses under the Farm Basis Analysis for LMU 11 2, LMU 13 1, LMU 14 1, LMU 14 2, and LMU 16 3 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
21	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
22	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
23	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
24	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	42	25	7
25	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
26	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
27	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	42	25	7
28	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
29	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	42	25	7
30	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
31	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	42	25	7
32	*8*	44	12.2	1.25	-10.13	-2.65	15	12	12	8	1	0
33	*5*	48	16.8	2.04	-4.79	-0.85	2	1	1	50	25	8
34	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
35	*8*	44	12.2	1.25	-10.13	-2.65	15	12	12	8	1	0
36	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
37	*5*	48	16.8	2.04	-4.79	-0.85	2	1	1	50	25	8
38	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
39	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
40	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100

Table A.7 Results of Regret and Robustness Analyses under the Farm Basis Analysis for LMU 11 2, LMU 13 1, LMU 14 1, LMU 14 2, and LMU 16 3 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
41	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
42	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
43	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
44	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
45	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
46	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
47	*6*	48	16.8	2.04	-4.79	-0.85	2	1	1	50	25	8
48	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
49	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
50	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
51	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
52	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
53	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
54	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	42	25	7
55	*2*	45	11.6	0.85	-15.42	-3.10	5	5	4	7	1	0
56	*9*	43	14	0.24	-29.85	-7.32	4	1	1	1	0	0
57	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
58	*8*	44	12.2	1.25	-10.13	-2.65	15	12	12	8	1	0
59	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
60	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100

Table A.7 Results of Regret and Robustness Analyses under the Farm Basis Analysis for LMU 11 2, LMU 13 1, LMU 14 1, LMU 14 2, and LMU 16 3 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
61	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
62	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
63	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
64	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
65	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
66	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
67	*4*	50	18.6	2.33	-2.91	-0.17	1	1	1	91	68	28
68	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	42	25	7
69	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
70	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
71	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
72	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
73	*3*	45	14.2	0.00	-18.46	-5.45	7	5	1	0	0	0
74	*8*	44	12.2	1.25	-10.13	-2.65	15	12	12	8	1	0
75	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
76	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
77	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
78	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
79	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
80	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100

Table A.7 Results of Regret and Robustness Analyses under the Farm Basis Analysis for LMU 11 2, LMU 13 1, LMU 14 1, LMU 14 2, and LMU 16 3 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
81	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
82	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
83	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	100	99	99
84	*5*	48	16.8	2.04	-4.79	-0.85	2	1	1	99	99	98
85	*5*	48	16.8	2.04	-4.79	-0.85	2	1	1	99	99	98
86	*2*	45	11.6	0.85	-15.42	-3.10	5	5	4	96	95	95
87	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
88	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
89	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
90	*7*	49	18.8	1.41	-14.65	-3.18	3	1	1	100	99	97
91	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
92	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
93	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
94	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
95	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
96	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
97	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
98	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
99	*6*	54	5.4	2.81	0.00	0.77	1	1	1	100	100	100
100	*1*	49	15.3	1.84	-7.43	-1.07	1	1	1	100	99	99

Table A.8 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 1

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
1	*1*	77	25.1	1.56	-6.31	-1.52	1	1	1	28	15	4
2	*1*	77	25.1	1.56	-6.31	-1.52	1	1	1	28	15	4
3	*2*	74	20.0	0.44	-13.21	-3.83	2	2	2	4	1	0
4	*3*	79	18.3	0.00	-29.10	-8.09	11	11	10	0	0	0
5	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
6	*5*	49	17.9	1.87	-6.09	-1.44	5	4	3	31	14	3
7	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
8	*6*	82	24.4	1.33	-14.26	-3.65	4	2	1	4	1	0
9	*5*	49	17.9	1.87	-6.09	-1.44	5	4	3	31	14	3
10	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
11	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
12	*8*	52	18.2	2.04	-5.11	-1.13	5	5	4	41	18	8
13	*2*	74	20.0	0.44	-13.21	-3.83	2	2	2	4	1	0
14	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
15	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
16	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
17	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
18	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
19	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
20	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31

Table A.8 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
21	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
22	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
23	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
24	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
25	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
26	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
27	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
28	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
29	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
30	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
31	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
32	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
33	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
34	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
35	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
36	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
37	*1*	77	25.1	1.56	-6.31	-1.52	1	1	1	28	15	4
38	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
39	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
40	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31

Table A.8 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 1 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
41	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
42	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
43	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
44	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
45	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
46	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
47	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
48	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
49	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
50	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
51	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
52	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
53	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
54	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
55	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
56	*2*	74	20.0	0.44	-13.21	-3.83	2	2	2	4	1	0
57	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
58	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
59	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
60	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31

Table A.8 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
61	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
62	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
63	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
64	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
65	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
66	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
67	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
68	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
69	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
70	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
71	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
72	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
73	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
74	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
75	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
76	*2*	74	20.0	0.44	-13.21	-3.83	2	2	2	4	1	0
77	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
78	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
79	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
80	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100

Table A.8 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 1 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
81	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
82	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
83	*4*	50	14.3	2.27	-2.75	-0.33	24	24	24	93	69	31
84	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
85	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
86	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
87	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
88	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
89	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
90	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
91	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
92	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
93	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
94	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
95	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
96	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
97	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
98	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
99	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100
100	*7*	57	5.6	2.60	0.00	0.59	1	1	1	100	100	100

Table A.9 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 2

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
1	*1*	164	66.5	0.40	-3.72	-1.02	22	19	14	64	35	14
2	*2*	159	79.1	0.00	-5.34	-1.50	14	10	4	34	18	5
3	*1*	164	66.5	0.40	-3.72	-1.02	22	19	14	64	35	14
4	*1*	164	66.5	0.40	-3.72	-1.02	22	19	14	64	35	14
5	*3*	134	52.2	0.87	-2.80	-0.69	22	13	8	86	62	25
6	*2*	159	79.1	0.00	-5.34	-1.50	14	10	4	34	18	5
7	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
8	*1*	164	66.5	0.40	-3.72	-1.02	22	19	14	64	35	14
9	*1*	164	66.5	0.40	-3.72	-1.02	22	19	14	64	35	14
10	*5*	144	53.4	1.50	-0.72	-0.03	12	8	6	100	99	91
11	*5*	144	53.4	1.50	-0.72	-0.03	12	8	6	100	99	91
12	*3*	134	52.2	0.87	-2.80	-0.69	22	13	8	86	62	25
13	*1*	164	66.5	0.40	-3.72	-1.02	22	19	14	64	35	14
14	*1*	164	66.5	0.40	-3.72	-1.02	22	19	14	64	35	14
15	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
16	*1*	164	66.5	0.40	-3.72	-1.02	22	19	14	64	35	14
17	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
18	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
19	*3*	134	52.2	0.87	-2.80	-0.69	22	13	8	86	62	25
20	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45

Table A.9 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 2 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
21	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
22	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
23	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
24	*3*	134	52.2	0.87	-2.80	-0.69	22	13	8	86	62	25
25	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
26	*5*	144	53.4	1.50	-0.72	-0.03	12	8	6	100	99	91
27	*6*	123	31.7	1.56	-1.26	-0.04	35	21	14	100	96	82
28	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
29	*6*	123	31.7	1.56	-1.26	-0.04	35	21	14	100	96	82
30	*6*	123	31.7	1.56	-1.26	-0.04	35	21	14	100	96	82
31	*4*	103	32.5	1.06	-1.83	-0.40	39	33	29	94	83	45
32	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
33	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
34	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
35	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
36	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
37	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
38	*6*	123	31.7	1.56	-1.26	-0.04	35	21	14	100	96	82
39	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
40	*5*	144	53.4	1.50	-0.72	-0.03	12	8	6	100	99	91

Table A.9 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 2 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
41	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
42	*6*	123	31.7	1.56	-1.26	-0.04	35	21	14	100	96	82
43	*6*	123	31.7	1.56	-1.26	-0.04	35	21	14	100	96	82
44	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
45	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
46	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
47	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
48	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
49	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
50	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
51	*5*	144	53.4	1.50	-0.72	-0.03	12	8	6	100	99	91
52	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
53	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
54	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
55	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
56	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
57	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
58	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
59	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
60	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98

Table A.9 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 2 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
61	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
62	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
63	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
64	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
65	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
66	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
67	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
68	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
69	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
70	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
71	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
72	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
73	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
74	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
75	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
76	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
77	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
78	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
79	*9*	145	47.4	1.81	-0.19	0.20	20	15	10	100	100	99
80	*9*	145	47.4	1.81	-0.19	0.20	20	15	10	100	100	99

Table A.9 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 12 2 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
81	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
82	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
83	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
84	*7*	57	8.0	1.75	-1.25	0.20	87	81	59	100	99	98
85	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
86	*10*	59	8.6	2.07	-0.51	0.34	86	79	58	100	100	99
87	*9*	145	47.4	1.81	-0.19	0.20	20	15	10	100	100	99
88	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
89	*10*	59	8.6	2.07	-0.51	0.34	86	79	58	100	100	99
90	*10*	59	8.6	2.07	-0.51	0.34	86	79	58	100	100	99
91	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
92	*10*	59	8.6	2.07	-0.51	0.34	86	79	58	100	100	99
93	*10*	59	8.6	2.07	-0.51	0.34	86	79	58	100	100	99
94	*10*	59	8.6	2.07	-0.51	0.34	86	79	58	100	100	99
95	*8*	126	24.5	1.84	-0.51	0.19	47	34	30	100	100	97
96	*10*	59	8.6	2.07	-0.51	0.34	86	79	58	100	100	99
97	*10*	59	8.6	2.07	-0.51	0.34	86	79	58	100	100	99
98	*10*	59	8.6	2.07	-0.51	0.34	86	79	58	100	100	99
99	*10*	59	8.6	2.07	-0.51	0.34	86	79	58	100	100	99
100	*11*	151	50.9	2.04	-0.04	0.34	18	12	7	100	100	100

Table A.10 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 2, LMU 14 3, and LMU 15 2

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
1	*1*	90	31.2	1.63	-4.17	-1.23	6	4	4	44	19	8
2	*2*	98	25.9	1.31	-6.32	-1.86	14	9	4	20	8	1
3	*3*	83	28.3	1.92	-2.72	-0.69	7	4	3	77	44	16
4	*2*	98	25.9	1.31	-6.32	-1.86	14	9	4	20	8	1
5	*3*	83	28.3	1.92	-2.72	-0.69	7	4	3	77	44	16
6	*2*	98	25.9	1.31	-6.32	-1.86	14	9	4	20	8	1
7	*4*	75	18.4	2.15	-1.19	-0.28	14	7	5	96	82	45
8	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
9	*4*	75	18.4	2.15	-1.19	-0.28	14	7	5	96	82	45
10	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
11	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
12	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
13	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
14	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
15	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
16	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
17	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
18	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
19	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
20	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78

Table A.10 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 2, LMU 14 3, and LMU 15 2 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
21	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
22	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
23	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
24	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
25	*8*	87	20.5	2.31	-0.51	0.06	31	25	11	100	99	85
26	*8*	87	20.5	2.31	-0.51	0.06	31	25	11	100	99	85
27	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
28	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
29	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
30	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
31	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
32	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
33	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
34	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
35	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
36	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
37	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
38	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
39	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
40	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97

Table A.10 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 2, LMU 14 3, and LMU 15 2 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
41	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
42	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
43	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
44	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
45	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
46	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
47	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
48	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
49	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
50	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
51	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
52	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
53	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
54	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
55	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
56	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
57	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
58	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
59	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
60	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50

Table A.10 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 2, LMU 14 3, and LMU 15 2 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
61	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
62	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
63	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
64	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
65	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
66	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
67	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
68	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
69	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
70	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
71	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
72	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
73	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
74	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
75	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
76	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
77	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
78	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
79	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
80	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78

Table A.10 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 2, LMU 14 3, and LMU 15 2 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
81	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
82	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
83	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
84	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
85	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
86	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
87	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
88	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
89	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
90	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
91	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
92	*6*	83	18.9	2.27	-0.76	0.01	32	30	27	100	99	78
93	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
94	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
95	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
96	*5*	64	8.6	2.38	0.00	0.22	61	54	52	100	100	97
97	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
98	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
99	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50
100	*7*	98	22.1	2.20	-1.47	-0.26	26	17	13	96	81	50

Table A.11 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 3

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
1	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
2	*2*	178	90.9	0.00	-4.63	-1.29	8	7	5	52	29	10
3	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
4	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
5	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
6	*2*	178	90.9	0.00	-4.63	-1.29	8	7	5	52	29	10
7	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
8	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
9	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
10	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
11	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
12	*4*	192	62.6	1.61	-0.61	-0.02	11	7	4	100	100	97
13	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
14	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
15	*1*	168	63.9	0.29	-3.27	-0.89	32	23	18	81	46	19
16	*5*	123	53.8	0.59	-2.44	-0.58	15	12	6	92	73	37
17	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
18	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
19	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
20	*5*	123	53.8	0.59	-2.44	-0.58	15	12	6	92	73	37

Table A.11 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 3 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
21	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
22	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
23	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
24	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
25	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
26	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
27	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
28	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
29	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
30	*3*	96	29.2	1.03	-1.63	-0.34	52	39	36	99	94	63
31	*6*	98	33.4	1.53	-0.75	-0.03	45	33	11	100	99	90
32	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
33	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
34	*6*	98	33.4	1.53	-0.75	-0.03	45	33	11	100	99	90
35	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
36	*4*	192	62.6	1.61	-0.61	-0.02	11	7	4	100	100	97
37	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
38	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
39	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
40	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100

Table A.11 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 3 (Continued)

Input Scenario (*I*)	Set of Management Practice (*M*)	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
41	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
42	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
43	*6*	98	33.4	1.53	-0.75	-0.03	45	33	11	100	99	90
44	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
45	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
46	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
47	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
48	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
49	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
50	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
51	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
52	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
53	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
54	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
55	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
56	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
57	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
58	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
59	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
60	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100

Table A.11 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 3 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
61	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
62	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
63	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
64	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
65	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
66	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
67	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
68	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
69	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
70	*9*	195	58.1	2.00	-0.20	0.18	13	9	8	100	100	100
71	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
72	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
73	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
74	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
75	*7*	49	8.3	2.09	-0.24	0.18	95	85	64	100	100	100
76	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
77	*9*	195	58.1	2.00	-0.20	0.18	13	9	8	100	100	100
78	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
79	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
80	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100

Table A.11 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 13 3 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
81	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
82	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
83	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
84	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
85	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
86	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
87	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
88	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
89	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
90	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
91	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
92	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
93	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
94	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
95	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
96	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
97	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100
98	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
99	*8*	101	26.2	1.87	-0.36	0.17	51	44	36	100	100	100
100	*10*	53	8.9	2.27	-0.06	0.29	94	86	58	100	100	100

Table A.12 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 15 1

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
1	*1*	247	85.5	0.12	-2.10	-0.54	36	28	20	95	86	44
2	*2*	235	101.2	0.00	-2.46	-0.65	30	20	14	92	76	33
3	*1*	247	85.5	0.12	-2.10	-0.54	36	28	20	95	86	44
4	*2*	235	101.2	0.00	-2.46	-0.65	30	20	14	92	76	33
5	*2*	235	101.2	0.00	-2.46	-0.65	30	20	14	92	76	33
6	*3*	273	98.9	1.32	-0.40	0.08	14	7	4	100	100	99
7	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
8	*1*	247	85.5	0.12	-2.10	-0.54	36	28	20	95	86	44
9	*2*	235	101.2	0.00	-2.46	-0.65	30	20	14	92	76	33
10	*1*	247	85.5	0.12	-2.10	-0.54	36	28	20	95	86	44
11	*2*	235	101.2	0.00	-2.46	-0.65	30	20	14	92	76	33
12	*2*	235	101.2	0.00	-2.46	-0.65	30	20	14	92	76	33
13	*2*	235	101.2	0.00	-2.46	-0.65	30	20	14	92	76	33
14	*3*	273	98.9	1.32	-0.40	0.08	14	7	4	100	100	99
15	*2*	235	101.2	0.00	-2.46	-0.65	30	20	14	92	76	33
16	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
17	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
18	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
19	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
20	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83

Table A.12 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 15 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
21	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
22	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
23	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
24	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
25	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
26	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
27	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
28	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
29	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
30	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
31	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
32	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
33	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
34	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
35	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
36	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
37	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
38	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
39	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
40	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93

Table A.12 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 15 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
41	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
42	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
43	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
44	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
45	*5*	108	45.4	0.82	-1.26	-0.22	51	39	34	99	97	83
46	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
47	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
48	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
49	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
50	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
51	*4*	130	31.9	0.77	-1.05	-0.16	71	58	42	99	98	93
52	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
53	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
54	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
55	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
56	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
57	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
58	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
59	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
60	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100

Table A.12 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 15 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/ annum)	Expected Revenue Regret ($/acre/ annum)	Maximum Erosion Regret (+) (tons/acre/ annum)	Maximum Erosion Regret (-) (tons/acre/ annum)	Expected Erosion Regret (tons/acre/ annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/ acre/annum (%)	Frequency of Erosion <1.5 tons/ acre/annum (%)	Frequency of Erosion <1.0 tons/ acre/annum (%)
61	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
62	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
63	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
64	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
65	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
66	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
67	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
68	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
69	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
70	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
71	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
72	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
73	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
74	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
75	*8*	276	98.8	1.62	-0.16	0.21	13	6	4	100	100	100
76	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
77	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
78	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
79	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
80	*3*	273	98.9	1.32	-0.40	0.08	14	7	4	100	100	99

Table A.12 Results of Regret and Robustness Analyses under the Farm Based Analysis for LMU 15 1 (Continued)

Input Scenario *(I)*	Set of Management Practice *(M)*	Maximum Revenue Regret ($/acre/annum)	Expected Revenue Regret ($/acre/annum)	Maximum Erosion Regret (+) (tons/acre/annum)	Maximum Erosion Regret (-) (tons/acre/annum)	Expected Erosion Regret (tons/acre/annum)	Frequency of Revenue >0.85 * *RVmax* (%)	Frequency of Revenue >0.90 * *RVmax* (%)	Frequency of Revenue >0.95 * *RVmax* (%)	Frequency of Erosion <2.0 tons/acre/annum (%)	Frequency of Erosion <1.5 tons/acre/annum (%)	Frequency of Erosion <1.0 tons/acre/annum (%)
81	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
82	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
83	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
84	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
85	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
86	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
87	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
88	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
89	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
90	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
91	*9*	121	29.4	1.80	-0.06	0.28	74	62	30	100	100	100
92	*9*	121	29.4	1.80	-0.06	0.28	74	62	30	100	100	100
93	*9*	121	29.4	1.80	-0.06	0.28	74	62	30	100	100	100
94	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
95	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
96	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
97	*9*	121	29.4	1.80	-0.06	0.28	74	62	30	100	100	100
98	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100
99	*6*	118	28.0	1.63	-0.20	0.19	75	64	36	100	100	100
100	*7*	95	18.0	1.68	-0.11	0.23	90	75	62	100	100	100