Protocol for BMP Assessment

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1 INTRODUCTION

Intensive agricultural operations have been implicated in water quality problems in many watersheds around the world (Osei and Keplinger 2008). In many agricultural watersheds, beneficial management practices (BMPs) are often prescribed to reduce sediment and nutrient losses from all farmlands, not only from intensive livestock or crop operations. In Alberta, Alberta Agriculture and Rural Development (ARD) is conducting a five-year (2007 to 2011) project aimed at evaluating BMPs for farms in the province (Olson and Kalischuk 2008).

As part of the BMP evaluation project, ARD is collaborating with the Texas Institute for Applied Environmental Research (TIAER) located at Tarleton State University in Stephenville, Texas to perform computer model simulations in order to evaluate the effectiveness in reducing sediment and nutrient losses and associated farm-level costs of implementing a variety of BMPs and combinations of BMPs. The purpose of this report is to outline recommended procedures for conducting BMP evaluations using the computer models selected for this project, in particular, to define the protocols for economic analysis, environmental analysis, and data collection.

Section 2 of this report provides an overview of the methodology used to evaluate BMPs with integrated computer simulation models. The field evaluation component of BMP assessments is not covered in this report. The subsequent sections discuss the main steps involved in computer simulations for BMP assessment as well as an outline of the computer modeling system used in this study. The report also includes a brief discussion of how the results obtained and procedures used in the present study can enable more rapid and effective assessment of BMPs in other watersheds.

2 OVERVIEW OF BMP ASSESSMENT METHODOLOGY

Computer modeling systems enable evaluation of a wide variety of BMPs and combinations of BMPs. In the present study an implementation of the Comprehensive Economic and Environmental Optimization Tool (CEEOT; Osei et al. 2000) framework that integrates the Soil and Water Assessment Tool (SWAT), Agricultural Policy Environmental eXtender (APEX), and Farm-level Economic Model (FEM) was selected for BMP evaluations. The implementation of CEEOT used in this study includes an integrated SWAT/APEX interface Program, the SWAPP component of the CEEOT modeling system. CEEOT enables users to simulate BMP adoptions throughout large watersheds by taking advantage of the capability of SWAT to simulate vast land areas, while still capturing intricate details of the BMPs due to the field scale precision afforded by the APEX model.

In order to effectively assess BMPs in any given watershed, the following steps are recommended:

i. Define problem statement and overall goals of the project, based on the underlying problems and issues – Section 3
ii. Define scenarios to be evaluated (baseline and alternative scenarios/BMPs) – Section 4
iii. Select appropriate computer models and other tools required for scenario evaluations – Section 5
iv. Obtain (collect) required data – Section 6
v. Calibrate and verify the models – Section 7
vi. Perform simulations (of baseline and alternative scenarios/BMPs) – Section 8
vii. Analyze the results (to determine BMP effectiveness) – Section 9
viii. Document findings

Steps 1 through 7 are addressed in greater detail in the sections indicated below. Since CEEOT has already been chosen as the modeling system for the project, Section 5 is simply a description of the CEEOT tool, rather than a discussion of how to choose an appropriate computer modeling system.

3 DEFINITION OF PROBLEM STATEMENT AND GOALS OF THE PROJECT

A goal is an observable and measurable end result having one or more objectives to be achieved within a more or less fixed timeframe (Business Dictionary 2008). The goals of the project depend directly on the problems or issues that need to be addressed. Consequently, an initial step in a BMP evaluation project is to define the problem statement, which should include a specific definition of the nature of the problem that needs to be addressed in the watershed. Then the goal(s) can be defined as the desired result(s).

Defining the goals of the project determines the list of scenarios or BMPs to be evaluated. For instance, if the problem in the watershed is an over application of manure phosphorus (P) resulting in excessive P losses in runoff and eutrophication of downstream surface waters, BMPs of interest would generally include reductions in manure application rates, supplemental nitrogen (N) fertilizer applications, and practices that reduce sediment losses from farmland.

A well defined project goal also provides qualitative or quantitative targets to which the outcomes of the project can be compared in order to determine how effective project activities have been in achieving what was intended. The goal of the project generally reflects the current and historical perspective of the watershed and where stakeholders would like to see their watershed in the future. The following are illustrative examples of watershed goals as related to water quality.

i. To reduce N and sediment loads originating from farmlands in the watershed by 50% using practices that do not entail significant cost to agricultural producers.
ii. To reduce annual total P losses from cropland to 5 kg ha^{-1} and annual total P losses from other agricultural lands to 1 kg ha^{-1}.
iii. To significantly reduce nutrient and sediment losses from agricultural lands from current levels.

As the last example shows, the goal does not have to include quantitative targets, though specific numeric targets that are reasonably achievable are generally helpful. Once the goals of the project have been defined, specific project objectives can be outlined and appropriate BMPs or scenarios can be identified to help meet those objectives.

4 SCENARIO DEFINITION

4.1 Overview of Scenario Definition

Once the goals of the project have been determined based on the available data from the watershed, scenarios can be defined to discover how best to achieve the objectives of the project. Most often, the preliminary data used to determine the goals of the project are adequate for determining what types of scenarios are pertinent. Once the scenarios to be assessed have been defined, additional data can be collected to evaluate them.

The scope of BMP assessments or watershed evaluations in general is defined primarily by the scenarios to be evaluated and the subject of interest on which those scenarios are imposed. In watershed assessments, the subject of interest is usually a selection of fields, farms, or the entire watershed. A scenario is essentially a unique specification of the factors that have potential impact on the subject of interest. In the context of computer model applications, each scenario is specified as a set of unique values for all input data variables, including farm management practices. In BMP evaluations, each BMP as well as each unique combination of BMPs is considered as a separate scenario. Thus BMPs are evaluated by first defining each relevant BMP or combination of BMPs as a separate scenario and then comparing the impacts of each of the scenarios to that of a reference scenario, often referred to as the baseline.

Scenarios need to be defined before data collection is completed, because the practices called for in each scenario determine to some extent the kinds of data that need to be collected. When defining scenarios, the following needs to be considered.

i. Baseline scenario. In order to determine the impact of any BMP or combination of BMPs, a reference point needs to be established. The reference point is often referred to as the baseline. The baseline is usually defined to represent the status quo, though this does not always have to be the case. Defining the baseline as the status quo means that comparisons between the scenarios to be evaluated and the baseline will represent comparisons between potential future conditions and current conditions.

ii. Detail of scenario specification. All scenarios must be specified with the same level of detail, otherwise comparisons made between scenarios may be erroneous. This means that all the model assumptions addressed in the baseline specification must be equally addressed during specification of each alternative scenario, and vice versa. Osei et al. (2000) contains a detailed listing of the model specifications that may be considered in scenario simulations.

To illustrate the importance of scenario specification, suppose that the following are two of the scenarios specified for a watershed.

Baseline: Status quo. Cows graze pastures and have access to a creek where manure may be directly deposited in the creek by grazing cattle.

Scenario 2: No creek access. Cows graze pastures with no access to the creek. The creek is fenced off so that livestock have no access to it. Consequently there is no manure deposition in the creek. Cows are provided water by means of watering troughs on the pasture. Grazing cattle also have access to a half-acre pond located on the pasture.

In this example, Scenario 2 is specified in greater detail than the baseline and this presents a number of problems. For instance, the baseline does not indicate whether cows have access to the half-acre pond or whether the pond currently exists; neither does it mention use of watering troughs. Furthermore, the baseline scenario does not specify how much access the cattle have to the creek and how often they actually enter the riparian area or the proportion of time they spend there. On the contrary, Scenario 2 specifies that the cows have zero access to the creek. In this hypothetical case, the results of the simulations, and consequently the evaluation of Scenario 2, depend on how the unspecified components in the baseline are handled by the modeling system. By default, any computer simulation model will “assume” some level of creek access and some level of cattle access to the pond or watering facility on the pasture. The above specification of the baseline is also problematic because, whereas it is known that the level of direct manure or manure nutrient deposition in the creek is zero under Scenario 2, the amount of manure nutrient deposition in the creek under the baseline is not known, and will, again, be dictated by the design of the modeling system.

4.2 Types of Scenarios

In agricultural watersheds, the scenarios of interest are often associated with farm production and management decisions. Prominent types of scenarios include nutrient management, livestock husbandry, cropland tillage, structural practices, and pesticide and other chemical use. However, exogenous factors such as government programs, taxes or price supports could also initiate producer behaviors that impact the environment and have definite implications for farm profits.

A list of the major scenario categories evaluated in watershed assessments or BMP evaluations is given in Table 4.1. The broad categories of scenarios shown in Table 4.1 were encountered in previous CEEOT applications (Osei et al. 2003a; Osei et al. 2003b; Saleh et al. 2000; Gassman et al. 2006; Saleh and Du 2004; Du et al. 2005). Thus the economic and environmental simulation models within CEEOT have been applied to evaluate the varied spectrum of scenarios indicated in Table 4.1. Scenarios specified for BMP evaluation projects may also include any reasonable combination of practices or specifications from one or more of the categories listed in Table 4.1.

Table 4.1. Scenario categories relevant for agriculture.

Code	Practice
H	Manure handling on-farm
[100]	Collection
[200]	Storage
[300]	Processing
M	Manure application or deposition on-farm
[100]	Application rate
[200]	Timing of applications
[300]	Mode of application
[400]	Pasture stocking density
D	Manure disposal off-farm
[100]	Haul off
[200]	Composting
[300]	Manure trading
F	Fertilizer application
[100]	Rate
[200]	Timing
[300]	Mode
P	Pesticide and other chemical use
[100]	Rate
[200]	Timing
[300]	Mode and form
T	Cropland tillage
S	Soil management
R	Ration modifications
B	Structural BMPs
L	Changes in livestock production systems
[100]	Livestock housing and husbandry
[200]	Grazing management
C	Cropping systems and sequence
[100]	Rotations
[200]	Spatial sequence
[300]	Vegetative cover
[400]	Brush management/control
X	Other exogenous factors
[100]	Fiscal policy
E	Farm Energy
Z	Scenario Combinations
A	Farm household management
W	Water use/management
O	Other farm management options

5 CEEOT MODELING SYSTEM

5.1 Historical Overview of CEEOT

CEEOT is a framework for analysis of environmental policy that addresses the economic and environmental effects of alternative policies or practices. The CEEOT framework was developed as part of a United States Environmental Protection Agency funded project called Livestock and the Environment: A National Pilot Project (NPP). The NPP was initiated in 1992 to help determine "technologies, policies, and institutional settings that can reduce potential environmental impacts of livestock production" while allowing the livestock industry to remain competitive in increasingly open world markets (Jones et al. 1993). This framework has since been generalized to all sectors of agriculture, including row crop production, pastureland, range management, and intense livestock and poultry production. CEEOT has also been used in forestry settings.

The CEEOT framework consists primarily of three modules: a policy module, an economic assessment module, and an environmental assessment module. The policy module receives input from constituency committees comprised of stakeholders in the watershed or region of interest. The economic assessment module consists of a farm-level economic module and, in some cases, an input/output economic model. The environmental assessment module includes a farm or field-scale environmental simulation model and a watershed-scale simulation model. In general, computer model implementations of the CEEOT framework are also referred to as CEEOT, although slightly different naming conventions have been used in the past to reflect the specific theme of each study.

In CEEOT implementations, stakeholders or landowners in various watersheds provide input in the policy formulation process. Policies determined within the policy module correspond to the goals and scenarios referred to above and take into account the set of technologies and practices available to agricultural operators. The first computer modeling system based on the CEEOT framework was developed for the analysis of issues relating to livestock and poultry. This modeling system, the Comprehensive Economic and Environmental Optimization Tool - Livestock and Poultry (CEEOT-LP) maintains the policy module of the CEEOT framework and includes specific economic and environmental simulation models. CEEOT-LP was subsequently augmented to enable its use in watersheds with row crops and no livestock, as well as for evaluation of alternative forestry practices.

In CEEOT-LP, the policy module interfaced with the rest of the computer modeling system through a set of specific policy scenarios. FEM (Osei et al. 2000) served as the economic module. FEM provides specific behavioral implementation of the scenarios for economic and environmental simulations and also simulates the economic impacts of the scenarios on livestock and poultry producers. FEM is an annual model that performs simulations of agricultural operations in a holistic manner. Output obtained from the economic model includes various revenue and cost components and farm net returns (Osei et al. 2000).

The APEX (Williams et al. 2000) model and the SWAT model (Arnold et al. 1998; 1999) are the two environmental simulation models that were employed in CEEOT-LP applications. APEX is a field scale model while SWAT is a watershed scale model. APEX is a multi-field augmentation of the Erosion Productivity Impact Calculator (EPIC) model, and was specially designed for simulation of livestock agriculture (Williams 1995). APEX was used in CEEOT-LP to simulate land uses receiving manure applications. Output from APEX, including edge-of-field sediment and agricultural nutrient losses, was routed in SWAT through the remaining land uses of the watershed to obtain total loadings at the output of the watershed of interest.

SWAT (Arnold et al. 1998) is a watershed-scale model developed to simulate continuous-time stream flow by dividing the watershed into a user-specified number of subbasins or sub-watersheds. Output from all three models was analyzed to determine the most appropriate choice of policies or practices for the study watershed. Both APEX and SWAT operate on a daily time step. Initially, CEEOT-LP was applied to livestock and poultry operations in several watersheds in Texas and Iowa. In later years, CEEOT applications were extended to forestry and row crop agriculture. These applications demonstrate that the framework is readily adaptable to other areas of interest.

5.2 Brief Description of CEEOT

In the current project, the most recent version of the CEEOT tool will be used. The latest version of CEEOT (Saleh and Gallego 2007; Saleh et al. 2007) is essentially a fully automated version of CEEOT-LP that is capable of simulating all agricultural and forestry land uses. The CEEOT simulation process uses SWAT data files generated by AVSWAT (Di Luzio et al. 2002) or the ARCSWAT program. As Figure 5.1 shows the current version of CEEOT fully integrates the economic and environmental models used in previous CEEOT applications. APEX and SWAT are integrated in the SWAPP module of the program to provide reliable simulation of detailed field processes and still take advantage of the large watershed routing capabilities of SWAT. Management information is transferred to FEM for estimation of the impacts of scenarios on key farm-level economic indicators. The Scenarios/Practices module in CEEOT captures the Policy module of the CEEOT framework.

The FEM-SWAPP linkage was developed by establishing a programming interface between the SWAPP module and FEM. Various routines were included in the CEEOT interface to transfer APEX and SWAT management files to FEM format in a Microsoft® Access database table. Furthermore, latitude and longitude coordinates representing the locations of hydrologic response units (HRUs) were transferred to FEM in the FEM options file. The latitude and longitude coordinates were used by FEM to determine which representative farms to simulate, since these farms differ from one region to another. Upon completion of FEM simulations, economic model output is used in conjunction with environmental indicators from the SWAT and APEX simulations to determine the cost-effectiveness of various scenarios.

6 DATA REQUIREMENTS AND DATA COLLECTION

6.1 Data Requirements

BMP evaluations require data on baseline practices and conditions, as well as the practices and conditions that are expected to occur under implementation of the BMP. As a general rule, the more detailed the information available, the more reliable the assessment of the BMP will be. However, it is better to use less information that is accurate rather than greater amounts of information that are potentially erroneous.

The main types of data required for BMP evaluations are tabulated in Table 6.1. The first column of Table 6.1 shows the specific data items required. The second column of the table indicates which of the three simulation models in CEEOT that data item applies to. The next column indicates whether the data item is a minimum (●), optimal (○), or preferred (√) requirement for BMP evaluations. Minimum requirements refer to those data items that are an absolute necessity for CEEOT applications. Optimal requirements refer to data items that are not absolutely required, but are needed for optimal BMP evaluations. Finally, preferred requirements are items that are not required for optimal BMP evaluations but are useful and would improve the reliability of the assessments. Preferred data items also leave less to chance since model defaults might sometimes be very different from the conditions in the study area. Preferred items are essentially more important in areas that depart from the norm. The last column indicates the status of data collection efforts for that data item for the present BMP evaluations in the Whelp Creek and Indianfarm Creek watersheds – whether all required data have been obtained (C), are incomplete (I), or that data item is not particularly relevant for the present study (NA).

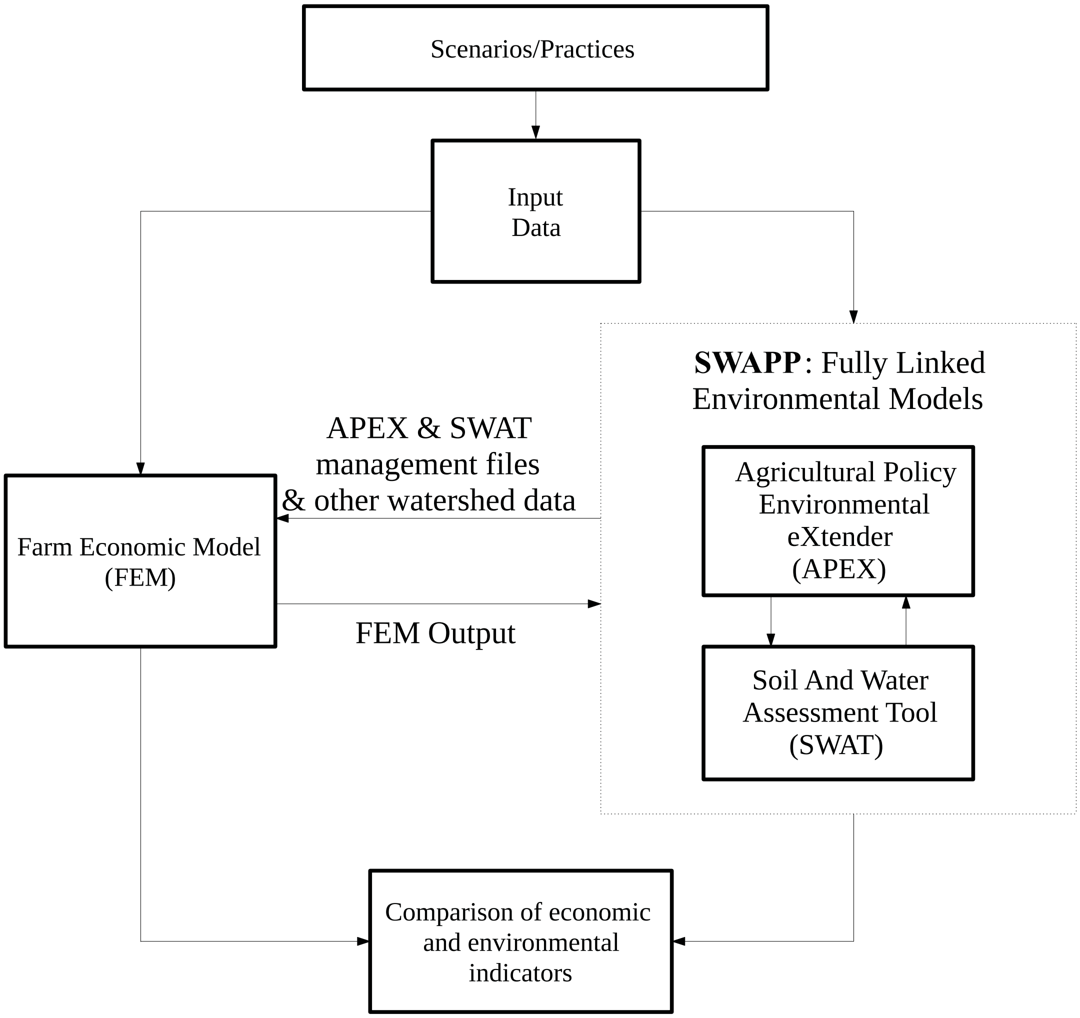

Figure 5.1. Schematic of the CEEOT modeling system.

6.2 Data Gaps and Limitations

The following sections outline the gaps and limitations that exist in the data set being developed for BMP evaluations in the Whelp Creek and Indianfarm Creek watersheds. In the present study, data gaps refer to instances where the required data is incomplete for purposes of CEEOT simulations. Similarly, data limitations refer to cases where the use of the existing data set is limited for various reasons even if the required data is available. Further explanations are given below. Plans for addressing each data gap or limitation are also indicated below.

6.2.1 Data Gaps and How They will be Addressed

Data items with a status value of "I" in Table 6.1 are items that have existing gaps as of the end of December 2008. The following are the plans for addressing each of these data gaps to ensure

Table 6.1. Data requirements for agricultural watershed assessments .

Data type	Applicable to	Priority[z]	Status[y]
Cropping Systems and Operations	APEX, SWAT, FEM	●	
Cropping systems	APEX, SWAT, FEM	●	C[1]
Crop operations	APEX, SWAT, FEM	●	C[2]
Operations performed by producer	FEM	○	NA[3]
Equipment used	APEX, FEM	○	C[1]
Supplies used (other than fertilizer or chemicals)	APEX, SWAT, FEM	○	C[1]
Discretionary fertilizer use	APEX, SWAT, FEM	○	C[1]
Other chemical use	APEX, SWAT, FEM	○	C[1]
Operations custom performed	FEM	○	NA[3]
Custom rates	FEM	○	I[4]
Crop (feed) yields	APEX, SWAT, FEM	○	C[1]
Crop agronomic (nutrient) requirements	APEX, SWAT, FEM	√	I[5]
Relationship between agronomic rates and crop yields	APEX, FEM	√	NA[6]
Feed Types and Nutrient Contents	FEM	○	
Feed types	FEM	○	C[7]
Feed nutrient contents	FEM	○	I[5]
Feed prices	FEM	○	C[8]
Prices of purchased feed	FEM	○	C[8]
Prices of feed sold	FEM	○	C[8]
Rules/behavior governing use of raised feed	FEM	√	NA[3]
Rules/behavior governing feed purchase	FEM	√	NA[3]
Livestock Systems	APEX, FEM	●	
Livestock inventory	APEX, FEM	●	I[9]
Livestock types	APEX, FEM	●	C[1]
Characteristics of livestock types	APEX, FEM	○	I[10]
Livestock sales	FEM	○	C[1]
Livestock purchases	FEM	○	I[10]
Death losses	FEM	√	NA[3]
Raised livestock	FEM	√	I[9]
Rules/behavior governing livestock inventory	FEM	√	NA[3]
Livestock operations	APEX, FEM	○	I[10]
Rules/behavior governing livestock handling/operations	FEM	√	NA[3]
Livestock nutrition	FEM	○	
Livestock nutrient requirements	FEM	○	I[10]
Bounds/restrictions on nutrient requirements	FEM	√	NA[3]
Bounds/restrictions on feed composition of rations	FEM	√	NA[3]

Table 6.1. Data requirements for agricultural watershed assessments (cont'd) .

Data type	Applicable to	Priority[z]	Status[y]
Manure nutrients and management	APEX, SWAT, FEM	●	
Manure production characteristics	APEX, SWAT, FEM	○	C[5]
Manure types: solid, liquid, direct deposition	APEX, FEM	○	C[5,9]
Manure proportions for each type	APEX, FEM	○	I[10]
Characteristics of manure in each type	APEX, SWAT, FEM	○	I[10]
Manure management options	APEX, FEM	○	I[10]
Characteristics/impacts of manure management options	APEX, FEM	○	I[10]
Manure nutrient losses/changes during storage and handling	APEX, FEM	○	I[10]
Manure nutrient losses after land application	APEX, FEM	○	I[10]
Plant availability of manure nutrients	APEX, FEM	○	I[10]
Structures and Facilities	APEX, FEM	○	
Buildings	FEM	○	I[10]
Livestock housing	FEM	○	I[10]
Characteristics of livestock housing	FEM	√	I[10]
Equipment housing	FEM	√	I[10]
Characteristics of equipment housing	FEM	√	I[10]
Commodity/grain/feed storage	FEM	√	I[10]
Characteristics of commodity storage	FEM	√	I[10]
Earthen structures	APEX, FEM	○	I[10]
Characteristics of earthen structures	APEX, FEM	○	I[10]
Other structures	APEX, FEM	○	I[10]
Characteristics of other structures	APEX, FEM	√	I[10]
Equipment Inventory and Characteristics	FEM	●	
Equipment inventory	FEM	○	C[1]
Equipment prices	FEM	○	C[1]
Equipment characteristics	FEM	○	I[9]
Land Uses and Characteristics	APEX, SWAT, FEM	○	
Land area owned	FEM	√	C[1]
Land area leased	FEM	√	C[1]
Land types	APEX, SWAT, FEM	○	C[1]
Pasture	APEX, FEM, SWAT	○	C[1]
Cropland	APEX, FEM, SWAT	○	C[1]
Hay fields	APEX, FEM, SWAT	○	C[1]
Woodland	APEX, FEM, SWAT	○	C[1]
Buildings/Homestead/Barren	APEX, FEM, SWAT	√	C[1]
Land use types	APEX, FEM, SWAT	○	C[1]
Manure disposal: liquid and solid manure	APEX, FEM	○	C[1]
Land receiving no manure/waste	APEX, SWAT, FEM	○	C[1]
Land used for grazing	APEX, SWAT, FEM	○	C[1]
Acreage for each land use	APEX, SWAT, FEM	○	C[1]
Rules/behavior governing land allocation to various uses	APEX, FEM	√	NA[3]
Agronomic/manure rates governing land uses	APEX, FEM	√	I[8]
Cropping systems on each land use	APEX, SWAT, FEM	●	C[1]
Rules/behavior governing land allocation/use for cropping systems	APEX, SWAT, FEM	√	NA[3]
Other exogenous parameters	APEX, SWAT, FEM	√	
Market conditions	FEM	√	NA[3]
Government policy	APEX, SWAT, FEM	√	I[8]
GIS maps	APEX, SWAT, FEM	●	
Land use/cover	APEX, SWAT	●	C[12]
Soils	APEX, SWAT	●	C[11]
Digital Elevation Map (DEM)	APEX, SWAT, FEM	○	C[11]
Producer location	APEX, SWAT	√	C[11]

Table 6.1. Data requirements for agricultural watershed assessments (cont'd) .			
Data type	Applicable to	Priority[z]	Status[y]
Weather information	APEX, SWAT	●	
Rainfall	APEX, SWAT	●	C[11]
Temperature	APEX, SWAT	●	C[11]
Data for calibration/validation	APEX, SWAT, FEM	●	
Water quality monitoring data	APEX, SWAT	●	C[11]
Water flow	APEX, SWAT	●	C[11]
Sediment	APEX, SWAT	●	C[11]
Nutrient concentrations	APEX, SWAT	○	C[11]
Other water quality characteristics	APEX, SWAT	○	C[11]
Farm budgets	FEM, APEX	√	C[8]

[z] Level of data requirement: minimum (●), optimal (○), or preferred (√)

[y] Status of data attainment: C=complete, I=incomplete, NA=not applicable. More specific indications are given in the numbered footnotes below:

[1] Data from farm surveys taken in 2008 included crops grown on fields on each farm as well as the field operations performed on those fields. Additional data from the two watersheds as well as subsequent farm surveys will help us determine the crop rotations (cropping systems) applicable to the watershed.

[2] While crop operation information in contained in farm surveys to varying degrees of detail, there is currently enough information in the surveys to use in developing input files for APEX, SWA T, and FEM.

[3] This data is used by FEM and is useful in situations where producers tend to custom hire specific operations and the custom costs are significantly different from the costs they would incur if they had performed the operation themselves. However, this is not always essential and does not appear to be needed for the present study. Economic model simulations and analysis are generally based on the most predominant assumption applicable to farms in the study area. If most farms perform operations themselves, that is the assumption used in the particular study.

[4] Custom rates are needed by FEM if certain operations are specified as custom performed. This data will be obtained from custom rate surveys applicable to the two watersheds in Alberta.

[5] This data item is needed by FEM for all crops. Preliminary data has already been obtained from ARD.

[6] This information is used to develop production functions relating yields to nutrient application rates so that yields can be adjusted accordingly. However, APEX yields can be used instead.

[7] This data was largely obtained from survey, but was also supplemented by data from ARD.

[8] Data has been obtained from ARD for a wide array of variables, including feed prices and nutrient contents, crop agronomic requirements, and current nutrient management recommendations. Additional data will be obtained on current regulations and other variables as indicated in the section on data gaps and limitations.

[9] This data was included in the farm surveys, but is incomplete, unless otherwise indicated as supplemented by other Alberta sources.

[10] Data on these variables was not included in the survey and will be obtained from ARD and other pertinent sources in Alberta.

[11] Detailed land use, soils, weather, and water quality information has been obtained for the two watersheds. Additional water quality data will be obtained in the coming years.

that all the data required for the CEEOT applications in Whelp Creek and Indianfarm Creek watersheds are available on time. Data items with a status value of "NA" are probably incomplete but are not particularly relevant for the present BMP evaluations in the two study watersheds.

Custom rates. Per acre costs of operations that are custom hired will be estimated from Alberta custom rate surveys or crop and livestock enterprise budgets that are applicable to conditions in the two watersheds. For operations where custom rates are needed for economic assessments but are not available, a brief survey of custom operators in the vicinity of the two study watersheds will be conducted.

Crop agronomic (nutrient) requirements. Crop agronomic requirements are needed for all three simulation models in CEEOT in order to simulate nutrient BMPs effectively. Preliminary data on crop nutrient requirements have already been obtained from ARD sources and these data will be evaluated to verify their completeness for the BMP evaluations in Whelp Creek and Indianfarm Creek watersheds.

Feed nutrient contents and livestock nutrient requirements. FEM contains default data on nutrient contents for a wide variety of cash crops and livestock feed ingredients. These default nutrient contents are based on decades of extensive research on North American feed ingredients. The nutrient content database will be updated if more specific data is available from sources closer to the two study watersheds.

Livestock inventory and purchases. The data available from the 2008 farm surveys contains adequate information on livestock sales, but only limited information on livestock inventories and purchases for the farms surveyed. Livestock inventory data are needed in simulations performed by all three models in CEEOT, but livestock purchase data are only required by FEM. A complete livestock count would be helpful in determining total nutrient loads in the two study watersheds. Efforts to obtain a more complete inventory of livestock in Whelp Creek and Indianfarm Creek watersheds are currently under way and will provide more reliable data on livestock inventories when completed. Livestock purchases for each farm type (e.g., feeder pigs, calves, replacements heifers) and other livestock characteristics (e.g., typical weight and age) will be obtained from livestock budgets applicable to Alberta farms. FEM defaults on livestock purchases are based on typical livestock husbandry practices in North America and could be used if more specific data is unavailable from the watersheds.

Livestock operations. Livestock operations are needed for FEM simulations but were not included in the farm surveys, partly because it is often difficult for farmers to accurately document all the different operations they perform on their individual farm and a primary objective of the farm surveys conducted in 2008 was to not overburden the survey respondents. For economic model evaluations, livestock operations that represent typical management practices on livestock farms in the two watersheds will be obtained from livestock enterprise budgets produced for Alberta farms.

Manure types and characteristics. Information on total manure production characteristics for various livestock species has been obtained from ARD sources. These data will be combined with information on the manure types reported in the farm surveys in order to determine specific nutrient applications for solid and liquid manure, as well as manure that is directly deposited on pasture lands. Proportions of solid and liquid manure will also be estimated based on typical livestock management practices on farms in the two study watersheds.

Manure management practices and nutrient losses. Information on current manure handling and storage practices, associated nutrient losses, and plant availability of manure nutrients is necessary for performing nutrient BMP evaluations. This information was not included in the farm surveys because farmers are often not able to relate nutrient losses to specific management practices without some technical guidance. Manure handling practices and associated nutrient losses are very pertinent for BMP evaluations, but were noted in Table 6.1 as optimal – rather than a minimum requirement – simply because the data is often available in published sources. For the present BMP evaluations in the two study watersheds, these data will be obtained from ARD sources. However, farm-level data are preferred and some farm-level data will be obtained from the BMP sites in the two study watersheds during the course of this project.

Structures and facilities data. Various characteristics of farm structures, buildings, and facilities are used for economic model simulations. These include prices, useful life, and repair and maintenance expenses, among others. Typical farm facilities include livestock and equipment housing, commodity storage barns, earthen structures, and other facilities. Data on these structures were not included in the surveys and will be estimated from livestock enterprise budgets applicable to Alberta.

Equipment characteristics. Farm survey data included information on equipment inventory on most of the farms surveyed as well as some limited data on equipment characteristics, primarily prices, and in some cases, width of field implements. Additional information on farm equipment characteristics that is needed for FEM simulations includes field efficiency, economic useful life remaining (in hours), repair and maintenance factors, and remaining (salvage) value factors, among others. Default values of these equipment characteristics are available in the FEM database for a wide range of farm equipment, but data more applicable to Alberta will be used, if available, based on assumptions used in the AgriProfit$ program.

Government policy. Information on current regulations and recommendations relating to manure management will be obtained from the appropriate agencies in Alberta. Existing regulations such as limits on manure applications on concentrated animal feeding operations will impact the costs and water quality effects of alternative BMPs.

6.2.2 Data Limitations and How They will be Addressed

As of December 2008, the required information on a number of data variables is adequate for model calibrations and simulations to be initiated. However, several of the data items indicated in Table 6.1 as complete will be updated with time. Thus the information available so far will only have limited use as revised data will be made available for the BMP evaluations on an annual basis until completion of the project. Information available on the following data items is particularly limited due to upcoming revisions.

Cropping systems. Farm survey data on cropping patterns, field operations, and yields will be updated through surveys and other information that will be obtained from the two watersheds on an annual basis. As more information becomes available model calibrations and simulations will be updated to more accurately reflect the cropping patterns applicable to Whelp Creek and Indianfarm Creek watersheds. The data available so far gives only a one-year history of crops and is thus inadequate to reflect any consistent crop rotations in the two watersheds.

Manure application. Information on rates, mode, and forms of manure applied on land will also be updated in future farm surveys. Updated manure application information for BMP and non-BMP sites will be used in BMP evaluations.

Water quality data. Currently, very limited water quality data is available from the two study watersheds. However, model calibration efforts are ongoing. As further water quality data are made available from existing water quality monitoring stations in the province, CEEOT simulations will be refined with the longer time series of water quality information.

6.3 Data Collection

In some watersheds data already exists on some of the variables and parameters – such as GIS maps, crop production and livestock inventories – listed in Table 6.1. Primary or secondary data[1] that already exists for relevant variables can simply be assembled and processed into the desired format for the study. However, information may not exist on some data items, such as on-farm management practices. In such situations it may be necessary to design a data collection instrument (survey or questionnaire) to collect new data.

Data collection efforts can entail substantial cost. However, greater amounts of reliable information will generally improve the reliability of BMP assessments. Consequently, there is a tradeoff between cost of data collection and reliability and usefulness of the results of the study. It is thus important to carefully design data collection methods in order to maximize the value of the information collected.

Whenever possible, a statistically valid sample of producers should be used if on-farm data needs to be collected. In most watersheds, a stratified sample design for sampling land owners is recommended. The following procedure is recommended for collecting farm data from producers.

i. Assemble data on key attributes of producers.
   Relevant attributes depend on the farm distributions and the scope of the study, and may include the following, among others:
   - Farm size (land area farmed)
   - Livestock herd size
   - Major soil group
   - Crop cover
   - Major tillage class (if known)

ii. Cluster farms into a reasonable number of groups.
   Clustering procedures in conventional statistical software can be used in this step (e.g. FASTCLUS procedure in SAS®)

iii. Arrange farms in each group in a random order.
   This can be accomplished with any recognized random number generator in a spreadsheet program or statistical package. Most compilers also include random number generators.

[1] Primary data refers to information obtained directly from the primary source, for example, data from a producer survey or interview. Secondary data, on the other hand, is information contained in publications or other media that have already assembled from primary or secondary data. Secondary data includes, for example, data from published media such as The Agricultural Census.

iv. Determine the sample size to survey in each group.
The minimum sample size required depends on the degree of variability in key attributes among the farms and the maximum level of error desired. Generally, the minimum sample size required *n* is given as:

$$n = \frac{(Z_{\alpha/2})^2 \sigma^2}{SE^2}$$

Where:
$Z_{\alpha/2}$ is the tabulated standard normal value for (100-α)% level of confidence,
SE is the predetermined maximum sampling error the user can tolerate
σ is the population standard deviation, which can be approximated by the standard deviation of any prior sample (McClave and Sincich 2006).

v. Collect data from the required number of farms in each of the farm clusters, proceeding from top to bottom in the randomized order until the required sample size has been reached for farms in each group.

The farm clusters developed in the above procedure can also be used to determine representative farms for FEM simulations and are also useful for analysis of output from the computer simulation models. If the population of farms in the study area is small enough, an attempt can be made to survey the entire population.

7 MODEL CALIBRATION AND VERIFICATION

Prior to simulation of the baseline or any alternative scenarios, all three computer simulation models within CEEOT (APEX, SWAT, and FEM) must be calibrated. Calibration is performed by using an iterative process to adjust model parameters within reasonable limits until model output and overall performance is consistent with the real world system being simulated. It is important to note that calibration is not merely a process of tweaking model parameters in order for the output of the model to match observed data. While model output may match observed data, the underlying mechanisms and parameters within the model may have been compromised during the calibration process. For effective calibration, the values as well as the interrelations between model parameters must conform to the accepted science. In this section, a brief overview of the calibration process is presented. A more detailed discussion of model calibration is given in Osei et al. (2000).

7.1 Overview of Model Calibration within CEEOT

The following steps represent the general procedure to be followed in calibrating any computer simulation models, particularly the models used within CEEOT. If automated calibration routines are available, they can be used to make the process more efficient, as calibration can turn out to be the most time consuming aspect of the entire BMP evaluation process.

i. Obtain Measured Data

Measured data for calibration includes measured values of environmental (water quality data) and economic (farm profits) indicators that will be compared to corresponding output indicators from computer model simulations.

ii. Determine “calibration scenario” – model specifications or input data that most likely resulted in the measured data.

The “calibration scenario” is the specification of model input to represent the conditions under which the measured data were collected. The “calibration scenario” may be different from the baseline. The “calibration scenario” may also be different from the status quo if, for instance, the only measured data available is the result of practices that predate current conditions.

iii. Establish Scientific Basis for Parameters

Adjustments in model parameters must be made within the confines of established science. Prior to actual calibration procedures, acceptable bounds and distributions of the parameters need to be established in order to prevent adjustment of parameters beyond reasonable limits. Existing scientific literature establishes acceptable ranges of values for parameters used in models as well as restrictions on the relationships between them. As far as possible, these constraints must be followed in model calibration. If it is necessary to include exceptions, modelers must provide fully documented justification for each case. For the convenience of users, some models, such as SWAT[2], provide limits on the range of input parameters to serve as a guide to users.

iv. Perform Simulations

The actual calibration process entails multiple simulations performed in a search for the most appropriate set of model specifications or parameter values. Use of professional judgment in addition to the established bounds on parameters will help minimize unnecessary or unfruitful simulations.

v. Compare Model Output to Corresponding Measured Data

At each step of the iterative calibration process, model output is compared to measured data. It is essential to compare not only the values, but also the correlations between different parameters to ensure that expected parameter distributions are not violated.

[2] See the SWAT User's Manual for further information.

vi. Repeat Steps d and e

In the absence of automated calibration routines, an iterative process is followed until the desired parameter configurations are reached. In the search of the optimal parameter values, widely accepted "goodness of fit" measures such as the F statistic or R^2 values can be used. Other criteria used widely in environmental model calibrations include the percent error (PE) and Nash Sutcliff efficiency (E) values, both defined below.

$$PE = \frac{(X_{ci} - X_{mi})}{X_{mi}} \times 100$$

$$E = 1 - \frac{\sum_{i=1}^{n} (X_{mi} - X_{ci})^2}{\sum_{i=1}^{n} (X_{mi} - \overline{X}_m)^2}$$

Where:
PE = percent error
E = the Nash-Sutcliffe model efficiency
X_{mi} = measured value
X_{ci} = predicted value
X_m = average measured values

A value of $E = 1.0$ indicates a perfect prediction, while negative values indicate that the predictions are less reliable than if one had used the sample mean instead. Users should select appropriate goodness of fit measures to use before initiating the calibration process. Furthermore, an acceptable range of these statistical (goodness of fit) measures should also be established prior to initiation of model calibration efforts.

vii. Document Findings of Calibration Process

As each model is being adequately calibrated, modelers must document the process undertaken as well as the results of the calibration effort. If any unusual assumptions were chosen, justification of these choices must be fully documented.

viii. Seek Professional Review

Professional project staff or other collaborating researchers should be consulted for their input on the results of the calibration once the calibration process has yielded meaningful results.

ix. Revise and Finalize Model Calibration

Input obtained from professionals acquainted with the relevant discipline should be incorporated in the process whenever possible. After all modifications have been applied, the documentation for the calibration process can be completed. In certain situations, calibration may not yield the desired model performance. In such cases, users need to use professional judgment to determine whether it is time to stop further calibration attempts and conclude that the "best" set of parameter values obtained thus far is adequate for the intended purposes.

7.2 Calibration of APEX and SWAT

Due to the highly integrated nature of APEX and SWAT within CEEOT, the two environmental simulation models must be jointly calibrated. Calibration of the APEX model makes use of edge-of-field flow, sediment, and nutrient loss measurements. In addition, APEX model output routed through the watershed via SWAT also yields information that can be compared with water quality data for the entire watershed.

Due to limitations on the time series of measured data on soil and water quality parameters, calibration is usually performed by restricting model simulations to the time period for which data are available for calibration and verification. In general, if the period for which measured data are available for calibration is sufficiently long, the user can split this period into two parts. One part of the data is used for calibration while the other part is used to verify that the calibration process was performed in accordance with the established science.

The following are key indicators to be considered in calibration of APEX and SWAT:

- Edge-of-field nutrient losses (particularly total N and total P and their components)
- Soil erosion and sediment losses at subbasin and watershed outlets
- Flow: subsurface, surface and return flow
- In-stream nutrient loads and concentrations

In certain situations, data from other watersheds can be used in calibration if those watersheds are similar to the study area and if adequate scientific and statistical procedures are used. This is particularly true for the APEX model where routing across varied topographies is not a significant component. In the current project, it appears that adequate data are being collected in Whelp Creek and Indianfarm Creek watersheds for computer model calibration efforts.

7.3 Calibration of FEM

Much like the environmental simulation models, FEM is calibrated by adjusting model parameters and comparing model simulation output with measured data. Key indicators that may be used in FEM calibration include the following:

- Feed costs
- Composition of ration for major livestock species
- Proportion of feed purchased
- How much of on-farm raised feed is used on the farm
- Time involved in field operations or labor hours involved
- Fuel and oil use for field operations
- Machinery repairs and maintenance costs
- Total cost of carrying out each field operation.
- Land area used for manure applications
- Manure application rates
- Fertilizer and chemical application rates
- Costs of fertilizer or chemical use
- Livestock product sales, including livestock numbers and weight, and sale of livestock products such as milk and eggs
- Crop and forage sales
- Total farm revenue
- Net returns to management
- Net cash flow
- Total cost
- Debt payment
- Cost of equity capital
- Net worth
- Various financial ratios: return on equity, return on assets, etc.

7.4 Model Verification

Model verification is performed, particularly for environmental models, to determine whether the calibration was completed successfully. If calibration is successful then not only are the simulated values similar to the measured values used in the calibration process, the simulated values for a different period of time should also mimic the measured values for that period of time.

As mentioned above under APEX and SWAT calibration, users can split measured data into two parts, use one part for calibration, and the other for verification. The same goodness of fit criteria mentioned above for calibration can be used for model verification as well.

8 SCENARIO SIMULATION

The CEEOT interface enables the user to define multiple scenarios within a single project. Each scenario included in the project can then be simulated and the results can be compared to the output associated with the baseline in the CEEOT interface[3]. Furthermore users can use standard spreadsheet software to compare the results of any two scenarios. For more information on definition and simulation of scenarios within the CEEOT user interface, the user is referred to the CEEOT User Manual, available for download at http://www.tiaer.tarleton.edu/transfer/CEEOT-SWAPP.

9 BMP ASSESSMENT AND EVALUATION

Once all defined scenarios have been simulated, BMPs are evaluated simply by comparing the economic and environmental indicators associated with each scenario to the corresponding values of the indicators associated with the baseline or other scenarios as needed. In general each scenario is simulated for a long enough period to encompass a reasonable range of weather patterns (wet and dry annual cycles). Then scenario comparisons are based on annual average values of the relevant indicators or other measure that is consistent across all scenarios simulated. For instance, suppose the following scenarios have been defined and simulated for a given watershed, with the corresponding average annual values from computer model output indicated (Table 9.1).

Given the scenario definitions and model output shown in Table 9.1, the following are the appropriate responses to various questions relating to BMP evaluations.

i. What is the impact of a filter strip on total sediment and N and P loads?
   Answer: Compare scenarios I and II:
   Impact of filter strip: 5000 lb reduction in total N per year, 2000 lb reduction in total P per year, and 2000 ton reduction in sediment per year

ii. What is the impact of a BMP consisting of filter strip and manure application at the P rate on edge of field P losses and farm profits?
   Answer: Compare scenarios I and IV:
   Impact of filter strip and P rate on P losses: 4 lb reduction in edge-of field P losses per acre per year
   Impact of filter strip and P rate on farm profits: Cost of $9000 per farm per year.

iii. Determine the impact of eliminating creek access on total N and P loads
   Answer: Cannot be determined from the five scenarios simulated because the only scenarios with eliminated creek access (IV and V) also include at least one or more BMP component not included in any other scenario, making it impossible to make direct comparisons for evaluating elimination of creek access unless other scenarios are simulated in addition to these five.

[3] Scenarios defined within a CEEOT project must be simulated individually. The CEEOT interface currently does not permit batch simulation of multiple scenarios.

i. Determine the impact of eliminating creek access and using rotational grazing on pastures on total N and P loads.
Answer: Compare scenarios I and V:
Impact of eliminating creek access and using rotational grazing: 7000 lb reduction in total N loads and 2500 lb reduction in total P loads per year.

ii. What is the impact of manure application at the N rate on edge of field nutrient losses (N and P losses)?
Answer: Cannot be determined from the five scenarios simulated, because the only scenario including manure application at the N rate (III) also includes at least one other BMP component that is not in any other scenario.

iii. What is the impact on total annual nutrient loads (N and P) of BMPs consisting of rotational grazing on pastures and manure application at the N rate on receiving crops?
Answer: Compare scenarios I and III:
Impact of rotational grazing and manure application at the N rate: 3000 lb reduction in total annual N loads and no change in total P loads.

The hypothetical example shown above indicates the importance of careful design of scenarios in order to obtain the BMP impacts desired. By simulating various combinations of BMPs very useful results can be obtained for developing appropriate policies for agriculture.

Table 9.1. Hypothetical specification and model output for five scenarios.

Scenario	I[z]	II	III	IV	V
			Model specifications		
Manure application rate (t ac^{-1})[y]	20	20	N rate	P rate	20
Filter strip	No	Yes	No	Yes	No
Grazing	Open access	Open access	Rotational	Open access	Rotational
Creek access	Unlimited	Unlimited	Unlimited	None	None
		Results (annual model output – edge-of-field losses loads at watershed outlet and farm profits)			
Edge-of field total N loss (lb ac^{-1})	25	20	22	27	20
Total N load (lb)	25,000	20,000	22,000	20,000	18,000
Edge of field P loss (lb ac^{-1})	5	3	5	1	4
Total P load (lb)	5,000	3,000	5,000	500	2,500
Edge of field sediment loss (t ac^{-1})	6	4	5	3	4
Total sediment load (t)	6,000	4,000	5,000	2,500	3,400
Average farm profits ($)	45,000	42,000	47,000	36,000	38,000

[z] Scenario I = baseline.
[y] 1 t ac^{-1} (tons per acre) = 2.242 Mg ha^{-1} (megagrams per hectare); 1 lb ac^{-1} (pounds per acre) = 1.121 kg ha^{-1} (kilograms per hectare); 1 lb (pounds) = 0.454 kg (kilograms); 1 t (tons) = 0.907 Mg (megagrams).

10 TRANSFERABILITY

Results from BMP evaluations can be adapted for watersheds that have similar attributes. As many watershed attributes as necessary can be used to determine the similarity of two watersheds for transferability purposes. However, due to cost considerations the key attributes to consider are the data items listed in Table 6.1 as minimum data requirements. Once a watershed has been determined to be similar to a previously studied watershed, results and inferences from the prior study can be adapted to the new watershed using standard statistical methods. For instance, agro-ecological metamodels[4] can be used to extrapolate BMP evaluations to similar watersheds.

If the results of a watershed study are transferable to another watershed, it means that much less effort needs to be expended to arrive at similar BMP evaluations in the second watershed. Whereas more detailed information may have been collected on all data items classified as minimum, optimal, or preferred parameters, only the minimum data requirements need to be met for the second watershed. More detailed information on the procedures entailed in transferability will be provided in a future report.

11 SUMMARY AND CONSCLUSIONS

As part of a five-year BMP evaluation project, ARD and TIAER will be using the CEEOT modeling system to evaluate a number of BMPs and combinations of BMPs that are applicable to farms in the province of Alberta. This document provides an outline of the procedures recommended for effective BMP evaluation using the CEEOT modeling system. The procedures outlined in this report will enable researchers and government staff with moderate expertise in computer simulation models to evaluate BMPs in the Whelp Creek and Indianfarm Creek watersheds, as well as other watersheds in Alberta where less detailed information is available. Future reports will address more specifically the procedures and issues involved in transferring the results and inferences of the present study to other watersheds for rapid BMP evaluations.

[4] Metamodels are statistical abstractions or a reduced form of an underlying more sophisticated model, such as a complex mechanistic environmental model or a sophisticated economic model.

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