Nutrient Beneficial Management Practices Evaluation Project

Volume 3
Modelling Study

Alberta Government

ACIDF Alberta Crop Industry Development Fund Ltd.

Application of the CEEOT Model to Alberta Watersheds

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2014

Citation

Jedrych, A., Osei, E., Heikkila, R., Saleh, A., and Gallego, O. 2014. Application of the CEEOT Model to Alberta Watersheds. Alberta Agriculture and Rural Development, Edmonton, Alberta, Canada. 145 pp.

Published by
Water Quality Branch
Irrigation and Farm Water Division
Alberta Agriculture and Rural Development
Lethbridge, Alberta, Canada

Printed in Canada

This report is also available at
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw11955

ACKNOWLEDGEMENTS

The completion of the CEEOT modelling study would not have been possible without the support of many individuals involved in the Nutrient Beneficial Management Practices Evaluation Project, including Alberta Agriculture and Rural Development staff (former and current) Syd Abday, Ki Au, Michael Bock, Phil Boehme, Tony Brierley, Wiebe Buruma, Janna Casson, Jollin Charest, Angela Chinn, Taren Cleland, Brian Coffey, Dana Coles, Brian Cook, Alexandra Crook, Sarah Depoe, Mike Ellefson, Clair Fitzpatrick, Francine Forrest, Paul Graveland, Lloyd Healy, Ward Henry, Bonnie Hofer, Daniel Itenfisu, Mark Kadijk, Andrea Kalischuk, Adelle Kientz, Len Kryzanowski, Larry Kwasny, Joanne Little, Kristen Lorenz, Rhonda MacKay, Gyan Mankee, Cory McIsaac, Brock McLeod, Cody Metheral, Lynda Miedema, Marilou Montemayor, Geoff Montgomery, Tanya Moskal-Hébert, Barry Olson, Gerald Ontkean, Lana Ontkean, Troy Ormann, Olubukola Oyewumi, Jim Parker, Brent Paterson, Longin Pawlowski, Jason Pentland, Murray Peters, Colleen Phelan, Mark Potvin, Mike Sajjad, Lawrence Schinkel, Barb Shackel-Hardman, David Spiess, Janelle Villeneuve, Trevor Wallace, Jamie Wuite, Karen Yakimishyn, Peter Yu, and Alison Zook; Texas Institute for Applied Environmental Research staff member Alex Tanter; and Agriculture and Agri-Food Canada staff members Sonia Salyzyn and Jason Vanrodaeys.

We very much appreciate the cooperation of many producers in the four study areas where water quality and field farm management data were obtained for this project. We also acknowledge the cooperation of the Municipal District of Pincher Creek and the County of Lacombe.

We are also very grateful for the significant funding from the Alberta Crop Industry Development Fund (Project 2007C012R) and from Alberta Environment and Sustainable Resource Development (formally Alberta Environment).

Finally, we thank Andrea Kalischuk and Barry Olson for overall project management and for reviewing the final report.

EXECUTIVE SUMMARY

Introduction

In 2007, Alberta Agriculture and Rural Development (ARD) initiated the 6-yr Nutrient Beneficial Management Practices Evaluation Project (BMP Project). Part of the BMP Project included a modelling component. The model used was the Comprehensive Economic and Environmental Optimization Tool (CEEOT), which was designed to evaluate the economic and environmental impacts of agricultural BMPs on water and soil quality at field and watershed scales. The CEEOT framework enabled interfacing among three separate computer models: Soil and Water Assessment Tool (SWAT), Agricultural Policy/Environmental eXtender (APEX), and Farm-level Economic Model (FEM) programs. This report summarizes the 5-yr period (2007 to 2011) of CEEOT modelling activities for the BMP Project.

The models were applied to the two BMP Project watersheds, Indianfarm Creek (IFC) and Whelp Creek (WHC), as well as the Lower Little Bow (LLB) field site. The objectives of the CEEOT modelling component of the BMP Project were to:

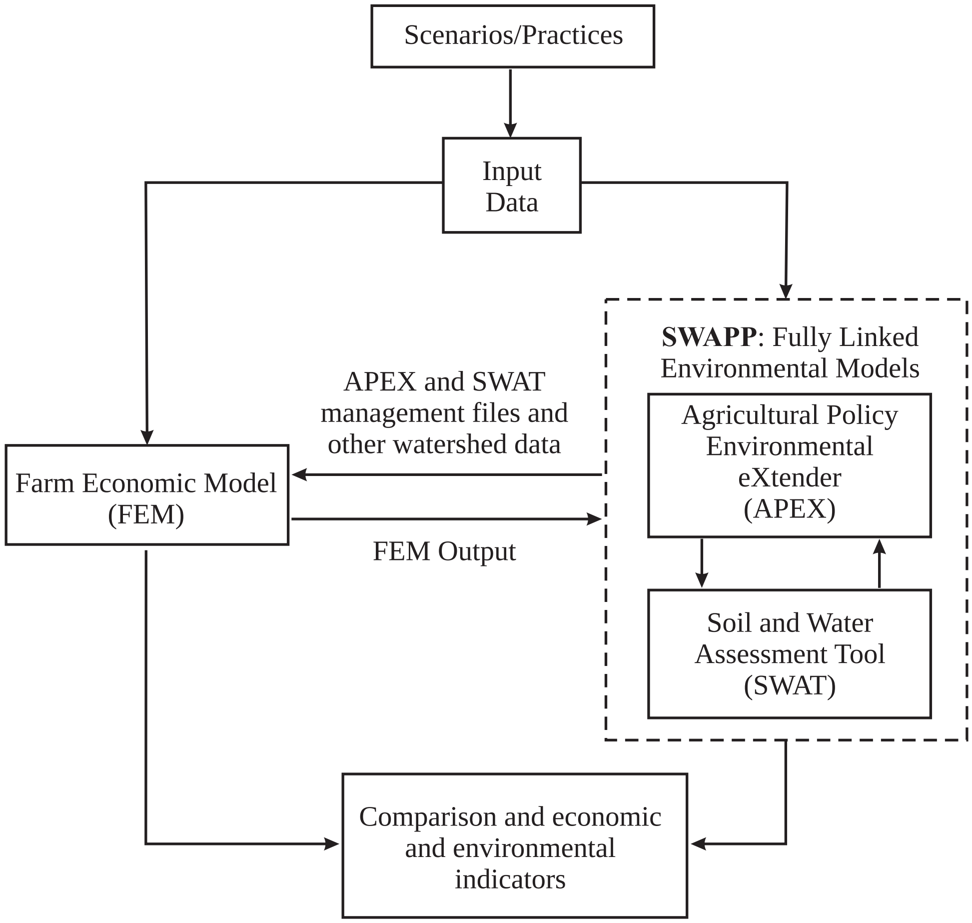
- Evaluate the performance of the CEEOT modelling system by comparing the model simulation results with field measurements collected during the BMP Project;
- Assess BMPs and simulation scenarios in terms of environmental effectiveness and associated economic impacts;
- Provide recommendations on the extrapolation and application of CEEOT modelling procedures and calibrated results; and
- Develop expertise to apply CEEOT on different watersheds in Alberta.

Development of Environmental and Economic Models

Environmental data for SWAT and APEX were derived from the BMP Project as well as a variety of other databases. Data entry included water quality and quantity, livestock inventory, topography, land management, soil physical and chemical properties, climate, and hydrology. The APEX and SWAT models were integrated into the SWAPP (SWAT/APEX Program) module of the program to provide reliable simulation of detailed field processes and still take advantage of the large watershed routing capabilities of SWAT.

The mean monthly flow rates and sediment and nutrient losses obtained from the calibrated SWAPP were compared with measured values (2007 to 2010) from the two watersheds and the LLB site to assess model performance. Two statistical methods were used to evaluate the performance of the SWAPP model. The IFC and WHC calibration results showed that SWAPP produced fairly good predictions of runoff, total suspended solids (TSS), nitrogen (N), and phosphorus (P) losses at the watershed outlets and during high flows. On the contrary, SWAPP predictions were less accurate at the field-scale, where flow was very low.

Representative farms were established for the two watersheds and the LLB site to serve as the basis for the FEM simulations and economic impact analysis. Most of the farm management data were obtained through producer surveys including field operations, crop yields, and livestock inventories, sales and purchases. Price data for most farm inputs and outputs were collected from ARD, Statistics Canada, Alberta Financial Services Corporation, and a number of other agencies. The FEM model was populated by using Visual Basic scripts and the CEEOT interface, which conveyed the results obtained from SWAT and APEX simulations. For FEM calibration, the average annual output from FEM was compared with farm cost and returns data for Alberta. In some cases, prices and other cost components were adjusted to better reflect Alberta conditions. Output from the FEM simulations was used in conjunction with environmental indicators from the SWAT and APEX simulations to determine the cost-effectiveness of various scenarios.



Schematic of the CEEOT modelling system.

Scenario Evaluation

In total, five scenarios were evaluated for either 30 (IFC and WHC) or 35 (LLB) years. Scenario 1 was the baseline scenario, which represented the status quo. Scenario 2 included only the BMPs implemented during the field study at participating farms. Scenarios 3, 4, and 5 were developed based on consultation with the team leads of the BMP Project. These three scenarios included a number of practices that were considered to be relevant for each watershed and addressed four main concerns: (a) manure management, (b) livestock management, (c) erosion control, and (d) irrigation efficiency and runoff. Scenarios 1 through 3 were similar among the watersheds; whereas, Scenarios 4 and 5 differed among the watersheds to reflect targeted concerns specific to each watershed.

Scenarios simulated in the CEEOT model for the Indianfarm Creek Watershed (IFC), Whelp Creek Sub-watershed (WHC), and Lower Little Bow River Field (LLB).

			Manure BMPs						Cow calf and riparian BMPs						
Watershed	Scenario	Field Study BMPs	Manure incorporation within 48 h	Manure AOPA setbacks	No application on snow	Soil nitrate nitrogen limits	Soil phosphorus limits	No manure applied in fall	Cattle restriction from creeks	Rotational grazing	15-m buffer strips	15-m grassed waterways	Wetland restoration	Reduced tillage in fall	Irrigation efficiency
IFC	2 (study)	X													
	3 (AOPA)		X	X	X	X									
	4 (cow-calf)		X	X	X	X			X	X	X	X			
	5 (P-limit)		X	X	X		X	X	X	X	X	X			
WHC	2 (study)	X													
	3 (AOPA)		X	X	X	X									
	4 (P-limit)		X	X	X		X	X							
	5 (riparian)		X	X	X		X	X			X	X	X	X	
LLB	2 (study)	X													
	3 (AOPA)		X	X	X	X									
	4 (P-limit)		X	X	X		X					X			
	5 (irrigation)		X	X	X		X					X			X

The environmental indicators of runoff depth and the loss of sediment (total suspended solids) and nutrients (total nitrogen and total phosphorus) were chosen to assess the scenarios. The results of the model simulations showed that the BMP scenario performance was site and watershed specific, and confirmed several conclusions from the field study.

Scenario 2 (field study BMPs) did not result in large water quality improvements at the watershed outlets. This reflected the few BMPs that were implemented in the watersheds, relative to the land base of the watersheds. In contrast, at the edge-of-field, significant water quality improvements were predicted by the implementation of a BMP.

Scenario 3 (AOPA – Agricultural Operation Practices Act) was more effective at improving water quality than Scenarios 1 (baseline) and 2, but not by much. The small improvement was because Scenarios 1 and 2 were very similar to Scenario 3, except for one distinguishing feature of manure application setbacks in Scenario 3. The environmental, and to a lesser extent, the economic impacts of AOPA were shown to be predicated upon the distribution of manure application fields and common bodies of water, i.e., the more manure fields closer to water bodies, the greater the impacts. This was illustrated as Scenario 3 resulted in more water quality improvements in WHC than elsewhere, because WHC had relatively greater numbers of manured fields and common water bodies. Another finding related to AOPA was that the soil nitrate nitrogen (NO_3-N) limits were largely unbinding in effect because most soils in the two watersheds were less than the thresholds given in AOPA during the 30- or 35-yr simulation horizon.

The addition of Scenario 4 in IFC with cow-calf and riparian BMPs resulted in the largest environmental gains and it was also the most cost effective scenario. Adding an agronomic P limit in Scenario 5 had little impact, as there were less than six fields in IFC that had manure applied.

The agronomic P limit in Scenario 4 of WHC resulted in some improvement in comparison to the AOPA NO_3-N limit in Scenario 3. However, it was the buffer strips, grassed waterways, and wetland restoration in Scenario 5 that showed the greatest environmental improvements in WHC, albeit at a fairly significant cost.

For the LLB site, Scenarios 4 (agronomic P-limit) and 5 (irrigation management) were slight variations on the approach taken in the field for Scenario 2. Environmental and economic results were generally similar between the scenarios, confirming that soil P levels can be reduced and water quality improved at the site if manure was no longer applied. However, there will be a significant cost to haul the manure for application elsewhere.

Additional observations from the models showed:

- Riparian and cow-calf BMPs that involved structural controls such as wetlands, off-stream watering, setbacks, buffer strips, fencing, and grass waterways resulted in significant reductions in sediment and nutrient losses.
- Phosphorus-based manure application limits were shown to be expensive to implement. In the P-based manure application scenarios, reduction of total P in the runoff was greater at the edge-of-field site than at the watershed outlets. This was most likely related to the variance in soil P concentrations, rather than the scale of observation. The LLB site was an edge-of-field site with high soil-test phosphorus (STP) concentration (>200 mg kg^{-1}) that was reduced in

the model scenario; whereas, the watersheds (IFC and WHC) had low soil P concentrations and lower reduction of total P in runoff.

- It was interesting to note that the model suggested that STP at the LLB site could be reduced by 50% within three years while Alberta-based research suggests it would take several decades to draw the STP levels down to background conditions.
- While detailed simulation capability provided the option of simulating complex combinations of practices, there were some limitations in comparison to the 'real world'.

All BMP scenarios resulted in negative net returns either from a decline in revenues or an increase in cost. The size of the representative farms affected the scale of the economic impact when they were reported on a per hectare basis. Cost-effectiveness estimates provided insight into which scenario generated the greatest loss reduction per dollar spent.

Cost-effectiveness ratios and trade-off assessment showed that some scenarios were superior to others. However, in general, optimal implementation of water quality improvement scenarios requires a combination of flexible scenario options, by starting with the most cost effective scenarios targeted to areas where the greatest benefit can be achieved and progressively using less cost-effective options until the watershed nutrient and sediment reduction goals have been attained.

Lessons Learned and Future Application of CEEOT in Alberta

Very low flow volumes were often well below the predictive ability of the simulation models used in this study. A significant amount of time was dedicated to improve SWAPP calibration results at the field-scale and watershed outlets. However, the final predictions of sediment and nutrient losses at this very detailed scale were not accurate enough to justify the time spent performing such refined calibrations at the field scale. Based on the experience gained from the SWAPP calibrations, it is recommended that future work be conducted for watershed outlets or sub-basin outlets with contributing areas at least the size of the WHC or IFC watersheds.

One of the primary objectives of the CEEOT application to the BMP Project watersheds was to develop a framework and protocol for rapid application of the model to other watersheds in Alberta. It is anticipated that future CEEOT applications in other watersheds in the province will not entail the same level of detailed effort and data collection as was the case for the BMP Project. Based on an inventory of the existing Alberta databases, the majority of the data are readily available at the different scales and formats required for use in CEEOT modelling.

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1 INTRODUCTION

Alberta crop and livestock producers face challenges of increasing input costs, market competition, and continued pressure to improve environmental stewardship (ARD 2014). A wide variety of beneficial management practices (BMPs) are promoted to producers to address environmental concerns; however, producers often find it difficult to evaluate the relative costs and benefits of BMPs. In addition, the effectiveness of BMPs to address environmental concerns is not well known under Alberta conditions. More information and analysis are needed to better promote BMP options for producers, and to assist policy makers in the development of appropriate programs and regulations dealing with environmental issues.

Comprehensive watershed management models can be effective in predicting the effects of implementing BMPs. Modelling the application of BMPs in a wide range of field conditions can inform land managers about farm practices that are best for their particular operations. Models can also save time and money since they can reduce the need for extensive field monitoring, which is expensive and often difficult to conduct. During the past decade, numerous models were developed to predict specific environmental processes (Williams 1995; Gassman 1997; Arnold et al. 1998; Renaud et al. 2006), such as stream flow and the concentration of sediment, nutrients, or pesticides in runoff at the field and watershed scales.

In 2007, Alberta Agriculture and Rural Development (ARD) initiated the Nutrient Beneficial Management Practices Evaluation Project (BMP Project). The purpose of this 6-yr study was to evaluate a variety of BMPs under Alberta conditions in terms of environmental effectiveness and associated costs. Part of the BMP Project included a modelling component. The model used was the Comprehensive Economic and Environmental Optimization Tool (CEEOT), which was designed to model BMPs in agricultural watersheds. The modelling component was carried out through collaboration between ARD and the developer of the model, the Texas Institute for Applied Environmental Research (TIAER). The CEEOT framework is one of the few models available that can evaluate the economic and environmental impacts of BMPs on water and soil quality at field and watershed scales. As well, it is able to simulate the effects of land-use changes on soil and water quality under snowmelt conditions.

The objectives of the CEEOT modelling component of the BMP Project were to:

- Evaluate the performance of the CEEOT modelling system by comparing the model simulation results with field measurements collected under the BMP Project;
- Assess different BMPs and simulation scenarios in terms of environmental effectiveness and associated economic impacts;
- Provide recommendations on the extrapolation and application of CEEOT modelling procedures and calibrated results; and
- Develop expertise to apply CEEOT on different watersheds in Alberta.

This report summarizes the 5-yr period (2007 to 2011) of CEEOT modelling activities for the BMP Project. Some of the information included in this report is also presented in ARD (2014).

1.1 Overview of the Nutrient BMP Evaluation Project

Two watersheds and two field sites were selected for the 6-yr (2007 to 2012) BMP Project. The watersheds were the Indianfarm Creek Watershed (IFC; 14,145 ha) in southwestern Alberta near Pincher Creek, and the Whelp Creek Sub-watershed (WHC; 4595 ha) in central Alberta near Lacombe (Figure 1.1). The WHC Sub-watershed used in this project was in the headwaters area of the larger Whelp Creek Watershed. Two field-scale sites were also selected northeast of Lethbridge: one in the Lower Little Bow River Watershed and the other in the Battersea Drain Watershed (Figure 1.1). The Lower Little Bow River Field (LLB) was about 83 ha in size and the Battersea Drain Field (BDF) was 65 ha in size. The watershed and field site selection included consideration of hydrological factors (e.g., high runoff potential), the presence of intense and diverse farming practices, the level of cooperation by local producers, travel distance to the watersheds, and access within the watersheds. Further details about the project are in ARD (2014).

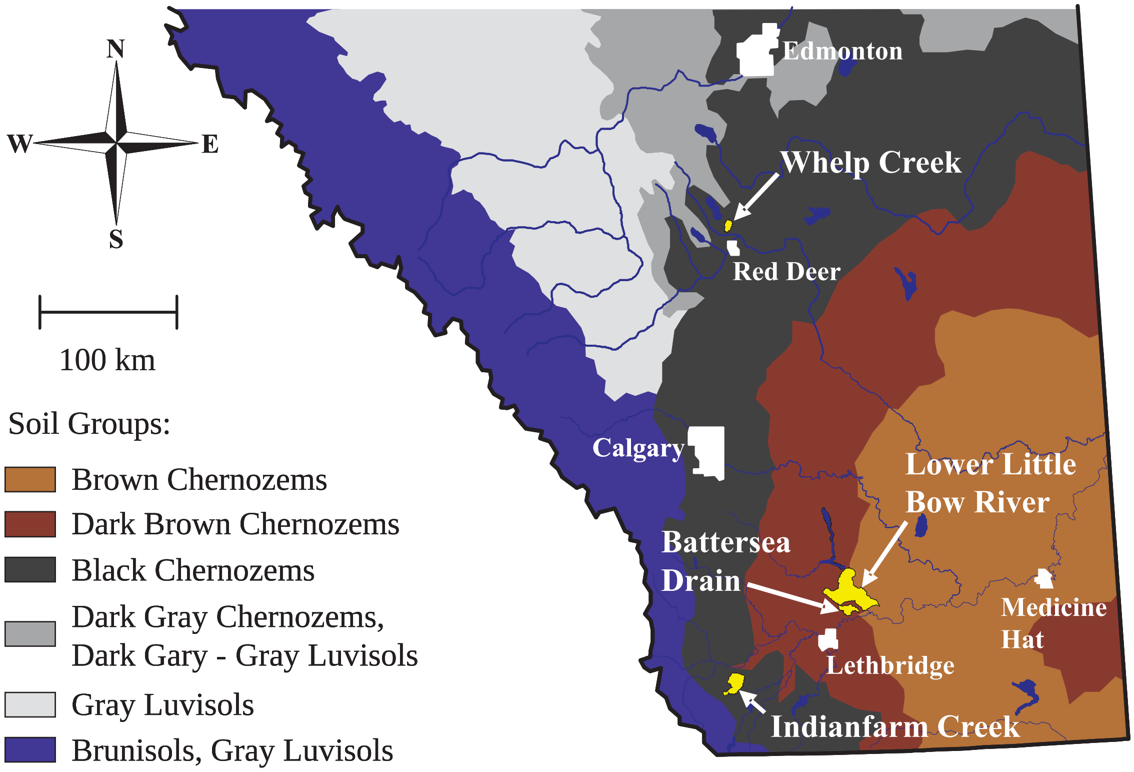


Figure 1.1. Location of the BMP Project watersheds in Alberta (ARD 2014).

The main objective of the BMP Project was to investigate the environmental effectiveness and the economic implications of BMPs under Alberta conditions. The main focus was on improving surface water quality; however, riparian quality, rangeland quality, and soil quality were also monitored at certain BMP sites. A before-and-after experimental design was used for the BMP Project. This first involved monitoring the existing land management practices for 2 or 3 yr to assess pre-BMP conditions, starting in 2007 for IFC, BDF, and LLB, and in 2008 for WHC. Then specific BMPs were implemented and the post-BMP conditions were monitored for 2 to 3 yr.

A total of eleven BMP sites were established in IFC (Figure 1.2). Of these, eight sites had water monitoring stations and field data from all these stations were used for modelling (Table 1.1). The number of water monitoring stations at the eight sites ranged from one to five stations. In addition, there were 10 watershed-wide monitoring stations, of which some were also used to monitor water at BMP sites. Four edge-of-field and two in stream monitoring stations were used at the BDF site, and a single, edge-of-field monitoring station was used at the LLB site (Table 1.1). In the WHC Sub-watershed, six BMP sites, two reference sites, and four watershed-wide monitoring stations were established (Figure 1.2). The number of water monitoring stations used at the WHC BMP and reference sites ranged from one to three stations. The WHC data from six BMP, two reference, and four watershed-wide sites were used for modelling (Table 1.1). Additional details about the location and types of BMPs relative to the modelling component are provided later in the report.

Each BMP monitoring site was instrumented to monitor surface water flow and quality. Riparian health, rangeland health, and soil nutrient status were also measured at some sites. In addition, field observations were made of farm-field operations, crop types and yields, livestock production, grazing management, and other management activities.

Implementation of the first three BMPs started in 2008 after a 2 yr pre-BMP monitoring phase at the BDF, LLB, and IFC study areas. However, the timeline for installation of the remaining BMPs varied from site to site and occurred from 2008 to 2011 (Figure 1.2). This variation was due to the need to collect additional pre-BMP data at some sites.

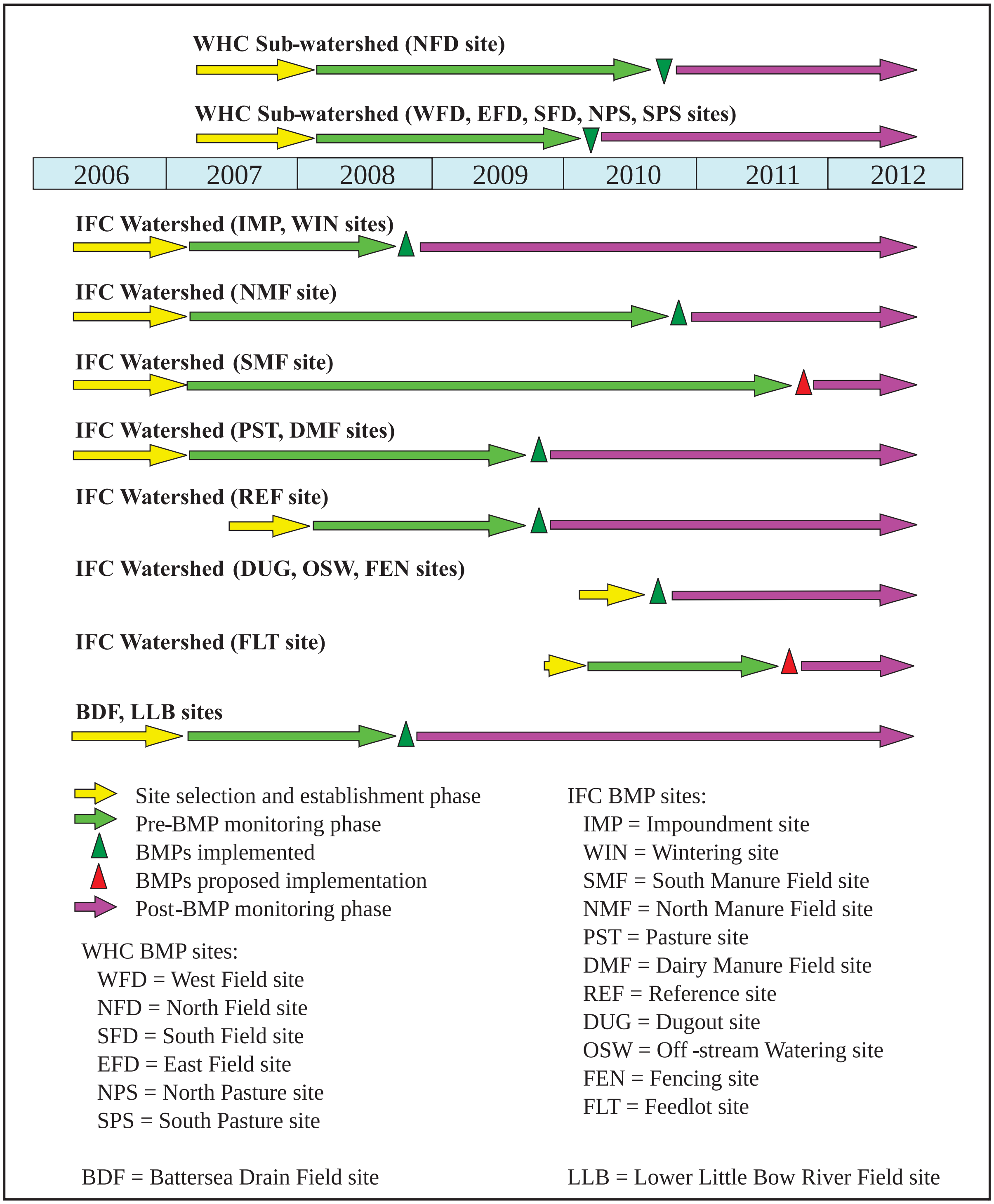


Figure 1.2. Timelines and types of BMPs implemented at the Indianfarm Creek (IFC) Watershed, the Whelp Creek (WHC) Sub-watershed, Lower Little Bow River Field (LLB), and Battersea Drain Field (BDF) (ARD 2014).

Table 1.1. Beneficial management practice (BMP) and watershed-wide water monitoring stations used for modelling in the Indianfarm Creek Watershed, Whelp Creek Sub-watershed, Lower Little Bow River Field, and Battersea Drain Field.

Station[z]	BMP site[y,x]	Watershed-wide site	Used for modelling	Station[w]	BMP site[y,x]	Watershed-wide site	Used for modelling
------------------ Indianfarm Creek ------------------				------------------ Battersea Drain Field ------------------			
1		Yes	Yes	201	BDF; us		Yes
2	IMP; ds		Yes	202	BDF; ds		Yes
3	IMP; ds	Yes		203	BDF; eof		Yes
4	NMF; eof		Yes	204	BDF; eof		Yes
5	PST; ds	Yes	Yes	205	BDF; eof		Yes
7	PST; ds			206	BDF; eof		Yes
8	PST; up						
9	PST; eof			------------- Whelp Creek Sub-watershed -------------			
10	PST; eof		Yes	301		Yes	Yes
11	WIN; ds		Yes	302	NPS; ds		
12	WIN; us	Yes		303	NPS; us	Yes	Yes
13		Yes		304		Yes	
14		Yes		305		Yes	
15	DMF; eof		Yes	306	EFD; ds		
16		Yes		307	EFD; eof		Yes
17	SMF; us			308	EFD; us		
18	SMF; ds		Yes	309	WFD; eof		Yes
19		Yes		310	NFD; ds		
20		Yes		311	NFD; eof		Yes
21	REF; eof		Yes	313	NFD; us		
22	IMP; us			314	SFD; ds		Yes
23		Yes		315	SFD; us		
24	FLT; ds			316	SFD; us		
25	FLT; ds			317	REF1; us		
26	FLT; us			318	REF1; ds		Yes
27	FLT; us			319	REF2; eof		Yes
28	FLT; us			324	SPS; eof		Yes
29	FLT; ds						
------------ Lower Little Bow River Field ------------							
101	LLB; eof		Yes				

[z] Station 6 was decommissioned early during the study.
[y] BDF = Battersea Drain Field; DMF = Dairy Manure Field; EFD = East Field; FLT = Feedlot; IMP = Impoundment; LLB = Lower Little Bow River Field; NFD = North Field; NMF = North Manure Field; NPS = North Pasture; PST = Pasture; REF = Reference; REF1 = Reference 1; REF2 = Reference 2; SFD = South Field; SMF = South Manure Field; SPS = South Pasture; WFD = West Field; WIN = Wintering.
[x] ds = downstream; eof = edge of field; us = upstream.
[w] Station 312 was decommissioned early during the study; Station 320 was not sampled; and Stations 321, 322, and 323 were at potential sites that were not selected for the study.

1.2 Overview of the CEEOT Modelling System

The CEEOT model was developed as part of a United States Environmental Protection Agency funded project titled the National Pilot Project on Livestock and the Environment (Jones et al. 1993; Osei et al. 2000a). It was first applied in the analysis of issues related to livestock and poultry (LP) and was named CEEOT-LP. The CEEOT-LP model was subsequently augmented to enable its use in watersheds with row crops and no livestock, as well as for evaluation of alternative forestry practices. 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 framework enables interfacing among three separate computer models: Soil and Water Assessment Tool (SWAT), Agricultural Policy/Environmental eXtender (APEX), and Farm-level Economic Model (FEM) programs. The two environmental models (SWAT and APEX) have been extensively evaluated and tested in many countries. Currently, there are more than 200 peer-reviewed publications available on these models (Gassman et al. 2007). Renaud et al. (2006) and Gordon et al. (2005) reviewed several models suitable for colder climate conditions, and gave SWAT a high ranking. The economic module in CEEOT (FEM) was tested and evaluated on different types of farms in Iowa and Texas in the United States (Osei et al. 2000a; Osei et al. 2003a). A summary of past applications of the CEEOT model to evaluate various agricultural and forestry BMPs in various watersheds is shown in Table 1.2.

The CEEOT simulation process uses SWAT data files generated by AvSWAT (Di Luzio et al. 2002) or the ArcSWAT program. The current version of CEEOT fully integrates the economic and environmental models used in previous CEEOT applications (Figure 1.3). The APEX and SWAT models were integrated into the SWAPP (SWAT/APEX Program) module of the program to provide reliable simulation of detailed field processes and still take advantage of the large watershed routing capabilities of SWAT (Osei et al. 2000b, 2008b). Management information was

Table 1.2. Summary of selected CEEOT applications.

Study area	Subjects of analysis
Upper North Bosque River Watershed, Texas [z]	Dry-lot dairies
Lake Fork Reservoir Watershed, Texas [y]	Pasture dairies
Upper Maquoketa River Watershed, Iowa [x]	Multiple livestock and crops
Alto Watershed, Texas [w]	Forestry
Duck Creek Watershed, Texas [v]	Broilers and pastured beef
Mineral Creek Watershed, Iowa [u]	Multiple livestock and crops
Buttrick Creek Watershed, Iowa [t]	Crops
Tipton Creek Watershed, Iowa [s]	Crops
Texas [r]	Animal feeding operations
Ohio River Basin [q]	Animal feeding operations
Walnut Creek Watershed, Iowa [p]	Crops

[z] Pratt et al. 1997, Osei et al. 2000b, Osei et al. 2003b; [y] McNitt et al. 1999, Osei et al. 2003c; [x] Osei et al. 2000c, Keith et al. 2000; [w] Saleh et al. 2004; [v] Keplinger and Abraham 2002; [u] Gassman et al. 2003; [t] Osei et al. 2005; [s] Osei et al. 2006b; [r] Osei et al. 2008a; [q] Osei et al. 2006a; [p] Saleh et al. 2007.

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 (Saleh et al. 2003, 2008).

The FEM-SWAPP linkage was developed by establishing a programming interface between FEM and the SWAPP module. Several 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 the 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.

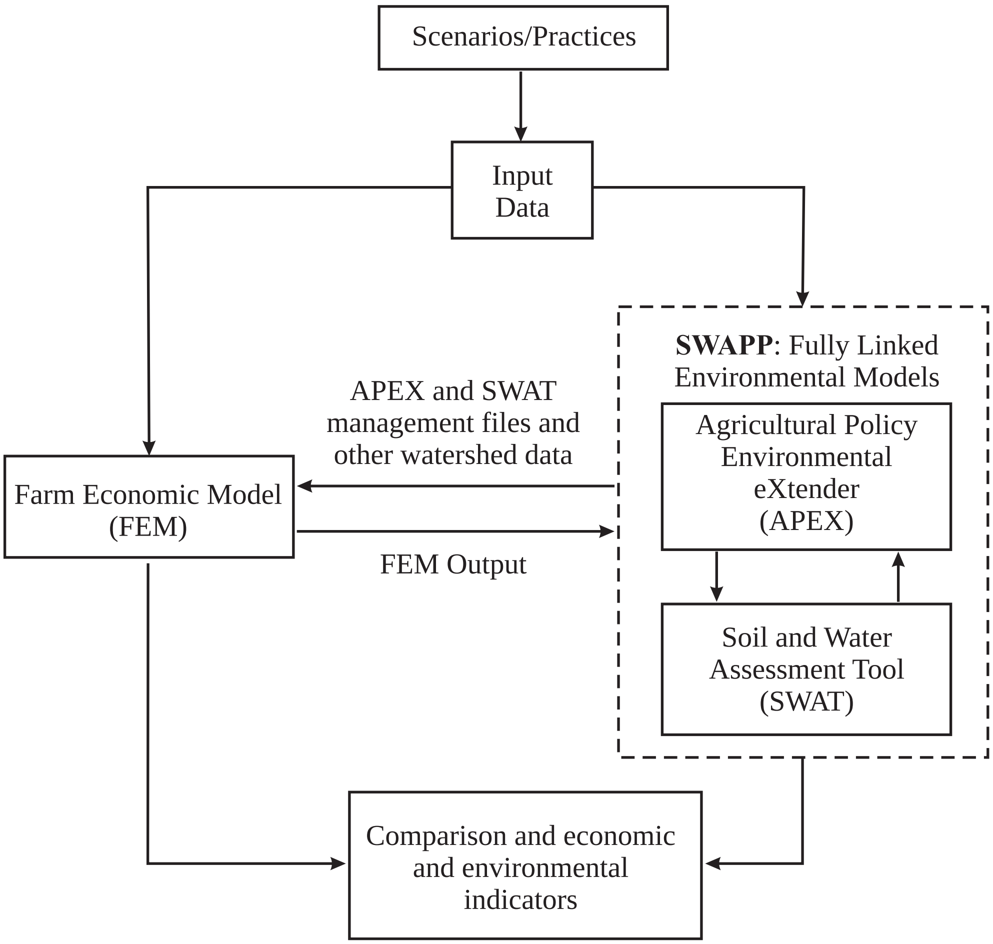


Figure 1.3 Schematic of the CEEOT modelling system.

2 SWAPP MODEL DATA DEVELOPMENT

During the 2007 to 2012 monitoring period of the BMP Project, a large amount of data was collected. However, due to time constraints, only the 2007 to 2010 data were used for CEEOT modelling. The modelling team agreed that the data were sufficient to evaluate the performance of the CEEOT model and to assess the effects of implementing BMPs on water quality in Alberta watersheds.

2.1 Preparation of GIS Format Model Input Files

2.1.1 Topographical Data

The IFC digital elevation model (DEM) data were obtained based on 25-m and 1-m grid resolutions. The 25-m grid DEM represented ground-surface topology or relief at a scale of 1:20,000, and it had relative horizontal and vertical accuracy (depending on terrain) of ±5.0 and ±3.0 m, respectively. The data were prepared by Alberta Environment and Sustainable Resource Development (formally Alberta Environment) in 2001 using the NAD83-10TM projection. The 1-m grid DEM was derived using remote sensing technologies called Light Detection and Ranging (LiDAR) and it had relative vertical accuracy of ±0.3 m (Figure 2.1a).

The WHC DEM data were obtained based on 25-m and 5-m grid resolutions. Similar to the IFC DEM, the 25-m grid DEM represented ground-surface topology or relief at a scale of 1:20,000, and it had relative horizontal and vertical accuracy (depending on terrain) of ±5.0 and ±3.0 m, respectively. The 5-m DEM data were derived from the 1998 1:30,000 scale aerial photography and it had a relative vertical accuracy of ±0.75 to 1.0 m (Figure 2.2a).

The LLB DEM was derived from aerial photography (Little et al. 2006), and it had grid resolution of 5-m and vertical accuracy of ±0.75 to 1.0 m.

The BDF DEM was generated from approximately 10,000 elevation points obtained using a differential global positioning system (GPS) and the “Point to Raster” functions in ArcGIS 9.3 software (Riemersma et al. 2002). A grid resolution of 2 m was selected based on the large number of elevation points available for the DEM production.

2.1.2 Land Management Information

In the BMP Project, land management data were collected at field, farm, and watershed scales. Watershed-scale data were collected by recording observed land-cover using AgCapture software (computer program developed by the former Prairie Farm Rehabilitation Administration, later re-named the Agri-Environment Services Branch) while driving throughout the watershed on an annual basis. Field- and farm-scale data were collected by interviewing volunteer producers and completing a questionnaire (ARD 2014). The interviews and questionnaires were carried out once, near the beginning of the project. In addition, field-scale management data were collected annually for all of the BMP sites.

The AgCapture data were used with the exiting Western GRAIN Transition Payment Program (WGTPP) 25-m grid and 2005 ortho-image data to outline polygon boundaries of unique land uses within the IFC and WHC watersheds. In total, 431 and 774 polygons were identified in the IFC and WHC watersheds, respectively (Figures 2.1b and 2.2b). For the LLB and BDF field sites, land uses were identified based on field observations. In total, two and five polygons were used at the two field sites, respectively.

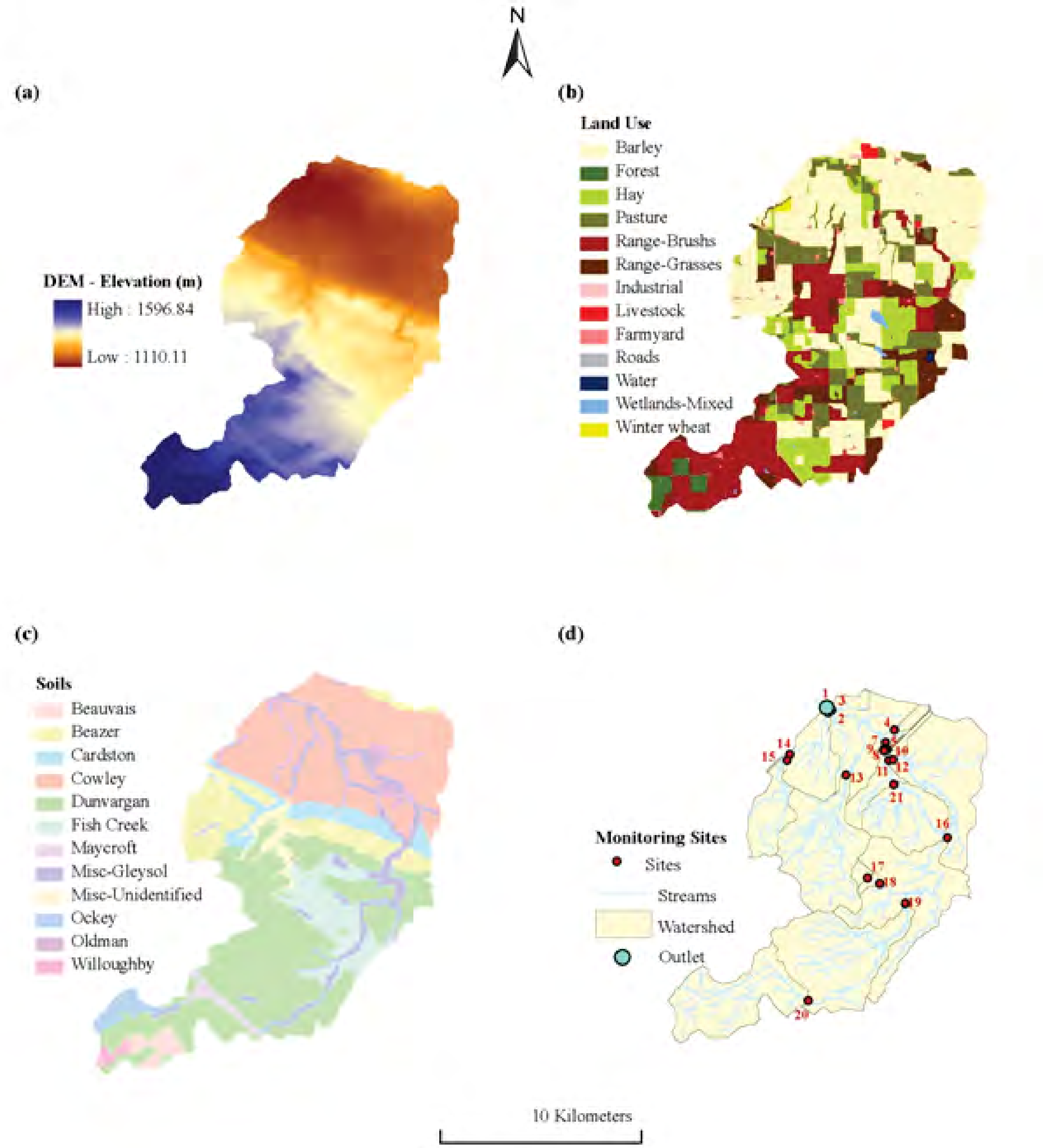


Figure 2.1. Maps of Indianfarm Creek Watershed showing (a) digital elevation model, (b) land use, (c) soils, and (d) sub-basins and water monitoring stations.

For the questionnaire, the producers were asked to provide land management and economic information. Two questionnaires were used: a long version for the producers with BMP evaluation sites on their property, and a short version for other producers in the watershed who were willing to participate in the survey (ARD 2014). In total, 13 producers were interviewed in the IFC Watershed, 27 in the WHC Sub-watershed, and one for the LLB site. These numbers represented

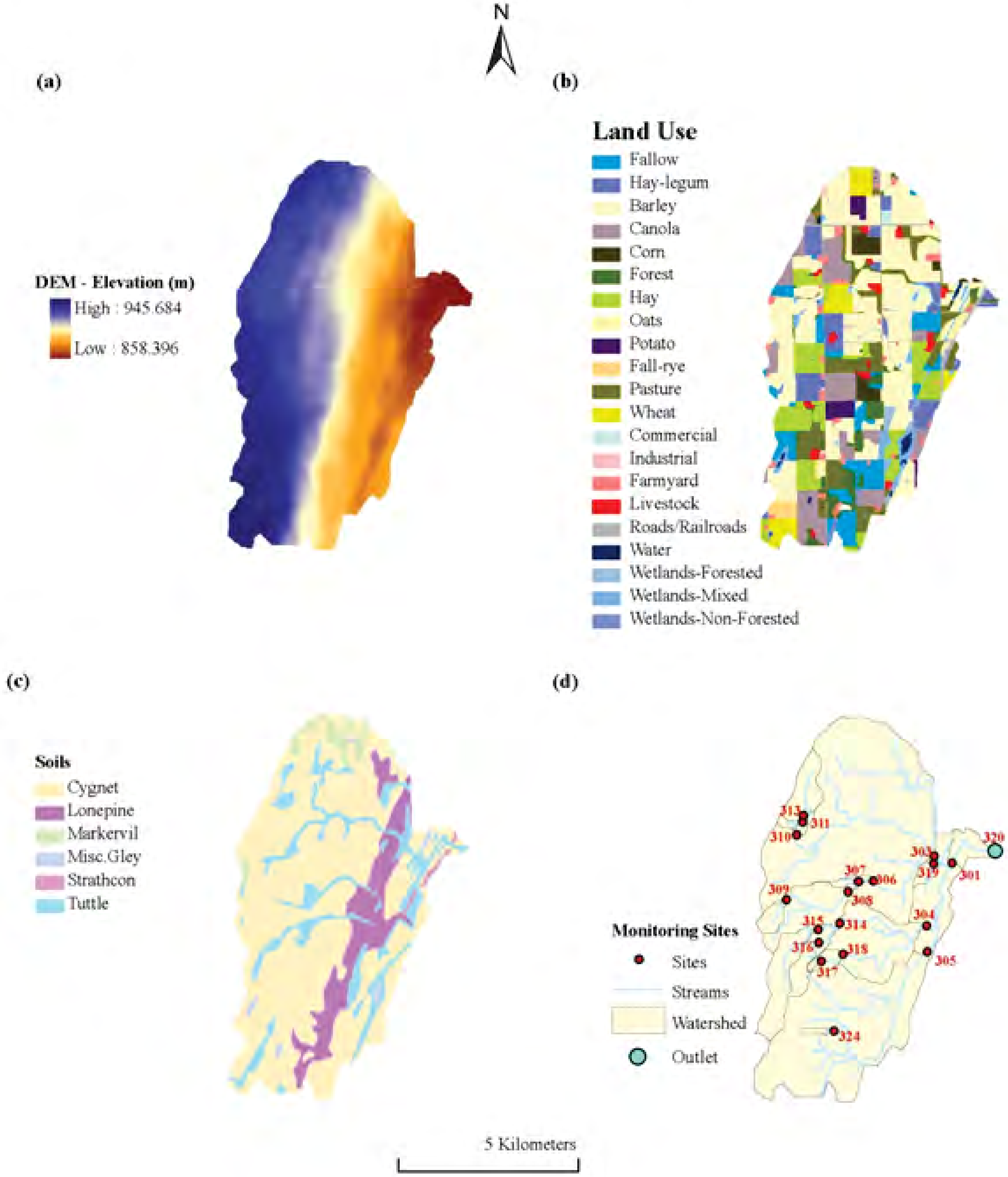


Figure 2.2. Maps of Whelp Creek Sub-watershed showing (a) digital elevation model, (b) land use, (c) soils, and (d) sub-basins and water monitoring stations (Station 301 was used as the outlet for CEEOT modelling).

about 18% of the producers in the IFC Watershed and 50% of producers in the WHC Sub-watershed. The following land management data were collected: (1) type of vegetation cover on each farm field, (2) schedule of field operations on selected farms, (3) information on livestock inventories and management, (4) fertilizer and manure application rates, (5) crop yields, and (6) type of equipment and machinery. The collected management data were assembled first into a tabulate format and then Visual Basic scripts were used to convert them into SWAT and APEX format input files.

2.1.3 Distribution of Soil Name Series

The Agricultural Region of Alberta Soil Inventory Database (AGRASID) represents the most accessible, digital format of soils information in Alberta (Alberta Soil Information Centre 2001). The data describes the distribution of soils within the agricultural areas of Alberta at a scale of 1:100,000. In the database, there are more than one-thousand soil series and each soil series has a list of soil properties for up to nine layers to a maximum depth of 2 m. In addition, each soil polygon provides information on the proportional distribution of soil series; however, there is no information on their geographical location within polygons. Brierley and Bock (2008) developed a method to modify AGRASID information and the distribution of soil series were displayed at a scale of 1:30,000 for the IFC and WHC watersheds (Figures 2.1c and 2.1c).

2.1.4 Hydrographical Data

Location of existing water bodies and ephemeral streams was represented by hydrographical data. The data were obtained from Alberta Environment and Sustainable Resource Development (Figures 2.1d and 2.2d) and were used with the DEM data in the AvSWAT program to help simulate the appropriate location of streams, sub-watershed boundaries, and monitoring sites.

2.1.5 Distribution of Ponds, Wetlands, and Reservoirs

The WGTPP grid and ortho-image data were also used to delineate distribution of water bodies within IFC Watershed and WHC Sub-watershed. Ponds and wetlands were defined as the intermittent or permanent water bodies located away from main channels and without water contribution from the upstream sub-basins. The majority of ponds were assumed to be dugouts. However, some ponds were assumed to be deep sloughs that had potential to store large volume of runoff and were surrounded by cultivated area. Wetlands were assumed to be local depressions under perennial cover such as pasture, shrub, or wooded areas. Reservoirs were defined as large permanent impoundments located on the main channels (Figures 2.3 to 2.5). In total, 74 wetlands and 70 ponds were delineated within IFC, 56 wetlands and 35 ponds within WHC, and no wetlands or ponds were defined within the LLB and BDF sites. In addition, five reservoirs were identified in IFC, five reservoirs were identified in WHC, and no reservoirs were identified in the LLB and BDF sites. Three of the reservoirs (IFC Sub-basins 20 and 27, and WHC Sub-basin 14) were constructed, and the other seven reservoirs (WHC Sub-basins 7, 9, 12, 18, and IFC Sub-basins 2, 12, and 15) were natural depressions or dugouts that had a stream flow through them.

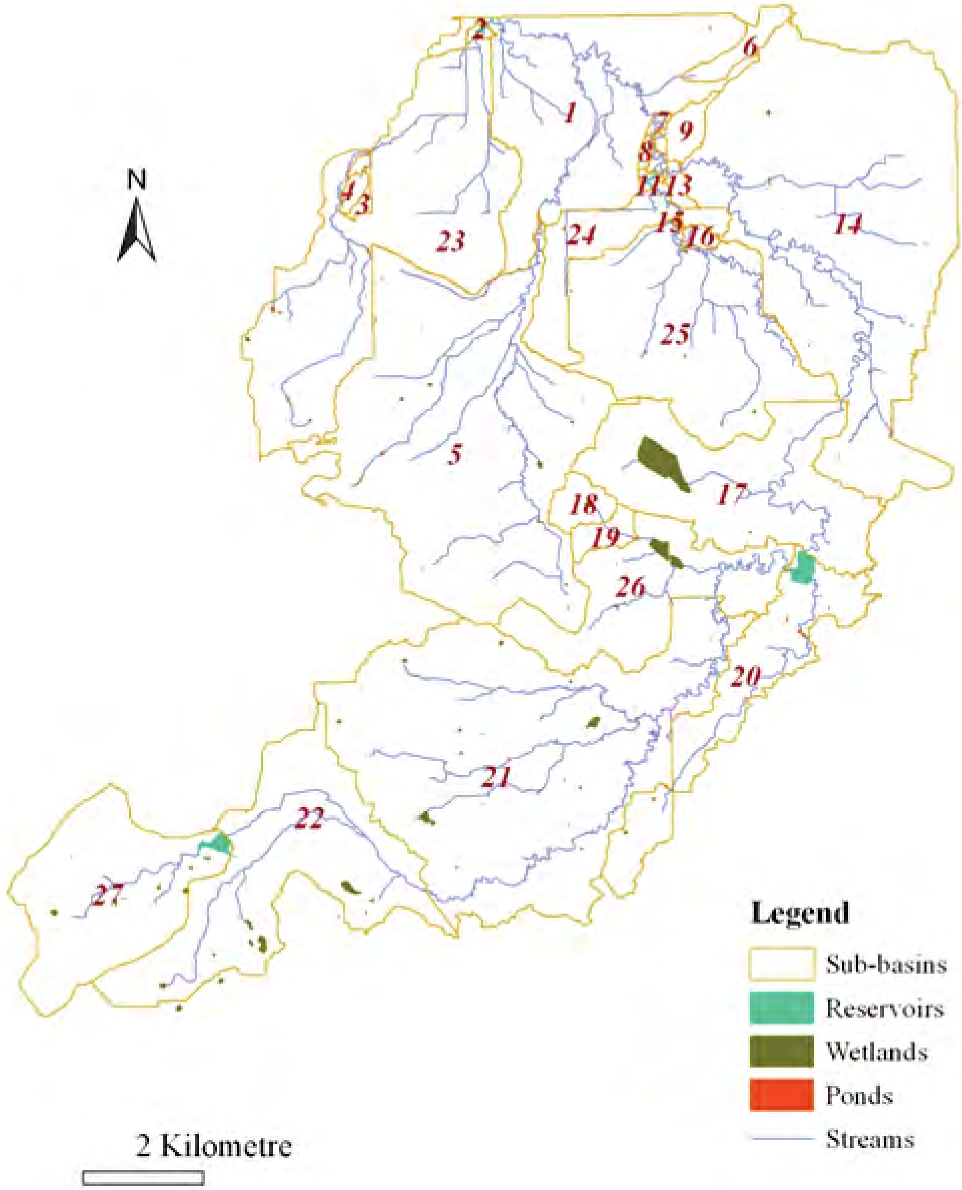


Figure 2.3. Distribution of ponds, wetlands, reservoirs, streams, and sub-basins within the Indianfarm Creek Watershed.

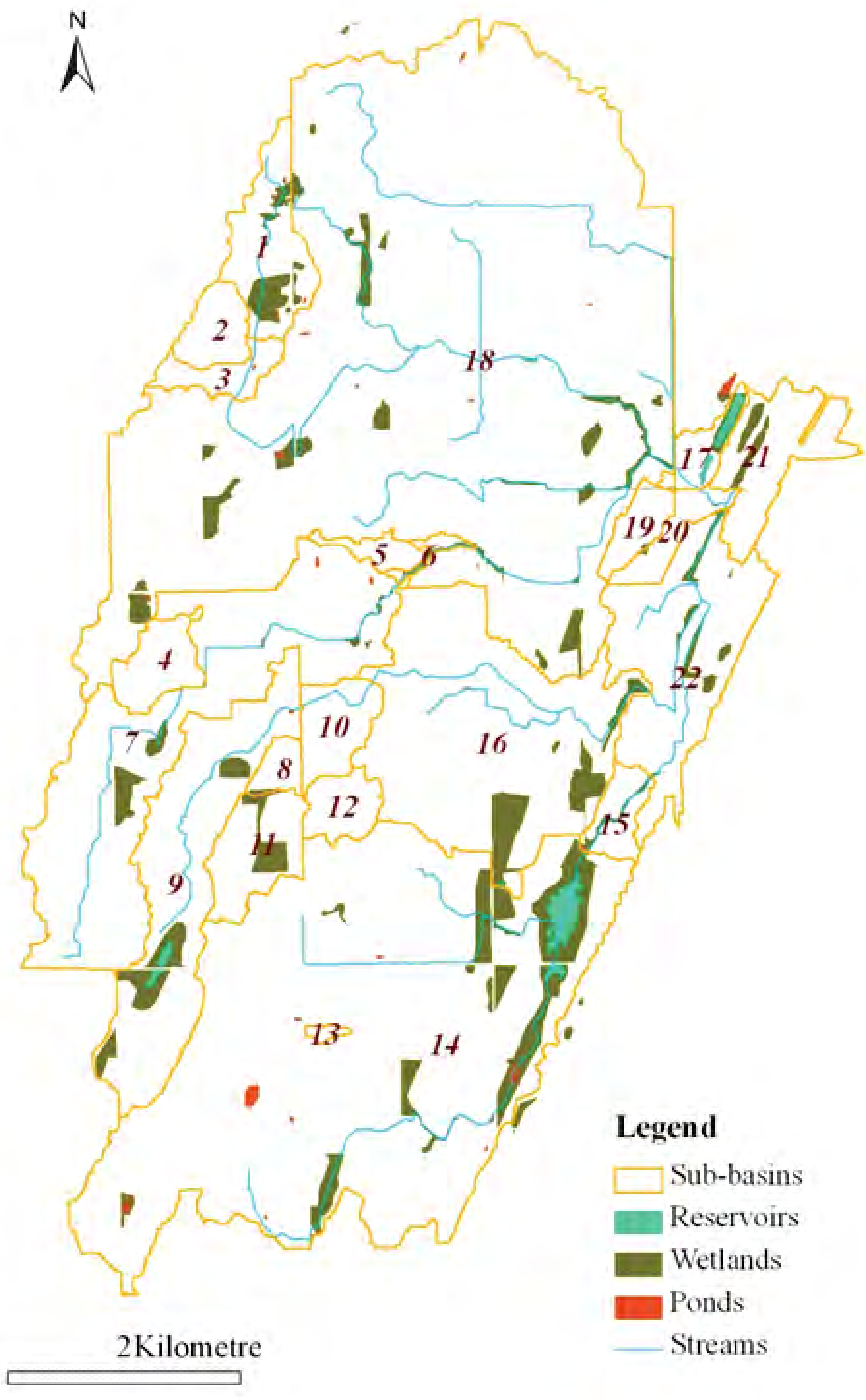


Figure 2.4. Distribution of ponds, wetlands, reservoirs, streams, and sub-basins within the Whelp Creek Sub-watershed.

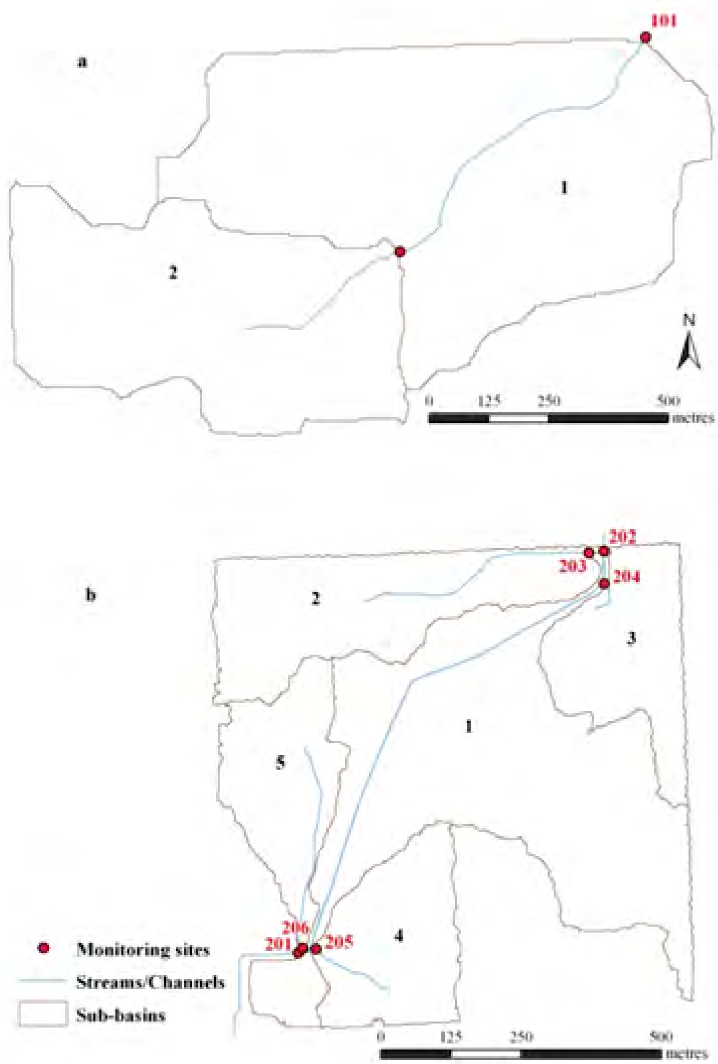


Figure 2.5. Water monitoring stations and sub-basins at the (a) Lower Little Bow River Field and (b) Battersea Drain Field.

2.2 Configuration of the Watersheds

Two similar area units are used to provide certain landscape input data to SWAT and APEX. The HRUs are used for SWAT and subareas are used for APEX. Basically, these units represent areas with similar biophysical characteristics, such as soil, land cover, management type, and field boundaries that generate various hydrological responses. The number and types of HRUs or subareas within a watershed can change as biophysical characteristics change, such as the implementation of BMPs. Where HRU's or subareas cross a boundary of two or more sub-basins, the hydrological output is proportioned and routed to the appropriate sub-basins. When SWAT is used, the watershed is partitioned into HRUs. However, APEX can perform better at a smaller field scale than SWAT. Therefore, in SWAPP, SWAT and APEX are used together and as a result, a combination of HRUs and subareas are required.

2.2.1 Indianfarm Creek Watershed

The IFC Watershed characteristics were derived using 1-m grid resolution LiDAR data. Prior to the watershed delineation process, the 1-m grid data were generalized into 4-m grid data in order to overcome the limitation of AvSWAT in handling analyses of large files (Di Luzio et al. 2002). For SWAT calibration, the delineated total drainage area of 14,145 ha was subdivided into 27 sub-basins (Figure 2.3; Table 2.1) and 154 different HRUs. The outlet locations for each sub-basin were

Table 2.1. Cross-reference among the Indianfarm Creek Watershed sub -basin IDs, monitoring site IDs, and selected site names.

Sub-basin ID	Water monitoring site ID	Drainage area (ha)	Site name[z]	Water monitoring site description
1	1	1060.9	Outlet	Instream, Watershed assessment
2	2	8.6	IMP	Impoundment BMP
3	na[y]	21.5		Not monitored
4	15	19.4	DMF	Edge of field
5	13	1957.6		In-stream tributary, Watershed assessment
6	4	67.1	NMF	Edge of field
7	5	9.4		Instream (upstream of site)
8	7	9.6		Instream
9	10	54.4	PST	Edge of field, Upstream of Old Corral BMP
10	9	12.6		Old Corral BMP, Downstream of site
11	8	5.8		Instream (upstream)
12	na	10.6		Not monitored
13	11	23.8	WIN	Instream (downstream of site)
14	12	2156.0		Instream (upstream of site)
15	na	2.1		Not monitored
16	21	18.8	REF	Edge of field
17	16	865.5		Instream, Watershed assessment
18	17	74.1		Instream (upstream of site)
19	18	56.0	SMF	Instream (downstream of site)
20	na	523.3		Not monitored
21	19	2209.8		Instream, Watershed assessment
22	20	1008.5		Instream, Watershed assessment
23	na	1332.0		Not monitored
24	na	281.2		Not monitored
25	na	1011.2		Not monitored
26	na	607.4		Not monitored
27	na	737.9		Not monitored

[z] Sites selected for calibration.
[y] Not applicable.

selected to match the location of the existing BMP Project water monitoring stations (Figure 2.1d and Table 2.1). For the SWAPP calibration, the watershed was divided into 31 different HRUs for SWAT and 144 different subareas for APEX. The new HRUs contained a total of about 7 ha of IFC area and the 144 subareas were in the remaining IFC area (14,138 ha).

2.2.2 Whelp Creek Sub-watershed

The above mentioned 5-m DEM data were used to delineate the WHC Sub-watershed and the sub-basin drainage areas and to estimate their landscape characteristics. Similar to IFC, the outlet locations for each sub-basin were selected to match the BMP Project water monitoring stations for SWAT calibration (Figure 2.2d). As the result, the 4595-ha WHC Sub-watershed area was subdivided into 22 sub-basins (Figure 2.4; Table 2.2) and 396 different HRUs. However, only 21

Table 2.2. Cross-reference among the Whelp Creek sub-basin IDs, monitoring site IDs, and selected site names.

Sub-basin ID	Water monitoring site ID	Drainage area (ha)	Site name[z]	Water monitoring site description
1	313	87.6		Instream (upstream of site)
2	311	35.6	NFD	Edge of field
3	310	29.8		Instream (downstream of site)
4	309	42.7	WFD	Edge of field
5	307	16.7	EFD	Edge of field
6	306	8.1		Instream (downstream of site)
7	308	395.8		Instream (upstream of site)
8	316	17.4		Instream, (upstream of site)
9	315	241.6		Instream (upstream of site)
10	314	48.5	SFD	Instream (downstream of site)
11	317	66.9		Instream (upstream of site)
12	318	33.4	REF1	Instream (downstream of site)
13	324	3.8	SPS	Edge of field, new in 2009
14	na[y]	1072.0		Impoundment outlet - not monitored
15	305	31.4		Instream, Watershed assessment
16	304	382.4		Instream, Watershed assessment
17	302	25.1		Instream (downstream ofsite - not active in 2009)
18	303	1708.5	TRIB1	Instream (watershed assessment, upstream for NPS)
19	319	26.8	REF2	Edge of field
20	301	31.1	Outlet	Instream, Watershed assessment (used for SWAPP modelling)
21	320	88.5		Actual watershed outlet
22	na	201		Instream - not monitored

[z] Sites selected for calibration.
[y] None available.

sub-basins (4501 ha) and 366 HRUs were selected for SWAT calibration since Station 320 (Sub-basin 21) was downstream from the monitored watershed outlet at Station 301 (Sub-basin 20). For SWAPP calibration, the 366 HRUs were modified and partitioned into 91 HRUs for SWAT simulation and 284 subareas for APEX simulation. The new HRUs contained about 354 ha of WHC area and the 284 subareas were in the remaining WHC area (4,147 ha).

2.2.3 BDF and LLB Field-scale Watersheds

The above mentioned 2-m and 5-m DEM data were used to delineate the BDF and LLB watersheds and the sub-basin drainage areas and to estimate their landscape characteristics. For SWAT calibration, the LLB site was divided into two sub-basins (Figure 2.5a) and eight HRUs. The areas for Sub-basins 1 and 2 were estimated at 51.4 and 31.4 ha, respectively. However, in SWAPP calibration, the eight HRUs were modified into two HRUs for SWAT and eight subareas for APEX. The calibration was conducted using monitoring data from Station 101. There was only one monitoring station (Station 101) at LLB; however, SWAT requires at least two sub-basins to run properly. Therefore, an artificial Sub-basin 2 was created with an outlet at the intersection of the two quarter-sections to remedy this limitation in SWAT. For SWAPP calibration, the above eight HRUs were modified into two different HRUs for SWAT and eight subareas for APEX.

The BDF field site was subdivided into five sub-basins. Station 202 was located on the Battersea Drain and was the downstream station for all the sub-basins in this quarter section (Figure 2.5b). In SWAT calibration, Sub-basins 1 and 4 had two HRUs each and Sub-basins 2, 3, and 5 had only one HRU each. Areas for Sub-basin 1 to 5 ranged from 7 to 26 ha. The SWAPP calibration for the BDF field site was not completed, as explained in Section 4.1, and no modified HRUs and subareas were created.

2.3 Development of Table Format Model Input Files

2.3.1 Climate Data

The SWAT and APEX climate input files required daily precipitation, maximum and minimum temperature, solar radiation, wind speed, and relative humidity data. For this project, historical data from 1981 to 2010 were estimated for all townships enclosed within the IFC, WHC, LLB, and BDF watersheds using the observed data from adjacent climate stations and an extrapolation procedure developed by Shen et al. (2000). In the procedure, the above weather parameters, with the exception of precipitation, were plotted onto a township network of grid points and then the average values were calculated inside polygons. The interpolation of precipitation values were based on a hybrid method, which combined inverse-distance weight and nearest-station assignment. The extrapolation method was able to predict the number of precipitation days per month and total daily precipitation amount reasonably well. These data files were used to conduct long-term BMP scenario simulations (Section 5).

For SWAT and APEX calibration proposes, additional data (temperature, relative humidity, and precipitation (rain)) were measured from 2008 to 2010 using weather stations installed in IFC Watershed (IWS1, IWS2, IWS3, and IWS4), WHC Sub-watershed (WWS1 and WWS2), and at the

LLB and BDF sites (ARD 2014). Due to lack of data availability prior to 2008 at these BMP weather stations, additional data were obtained for the 2000 to 2007 period from nearby exiting weather stations (Table 2.3). Snow precipitation, solar radiation, and wind speed datasets for WHC were obtained from the Environment Canada weather station Lacombe CDA 2 (Environment Canada 2011). For IFC, solar radiation records were obtained from Brocket AGDM (AgroClimatic Information Service 2009), and wind speed and snow precipitation data were from Pincher Creek AUT (Environment Canada 2011). Also, snow precipitation, solar radiation and wind speed datasets were obtained from the Lethbridge CDA station for BDF and LLB (Environment Canada 2011). The assembled model input data files included some climate data measured at the BMP Project sites and some at nearby weather stations.

From 2007 to 2010, annual precipitation varied from the 30-yr average (Environment Canada 2011) at the IFC, WHC, LLB, and BDF research sites (Table 2.4). For example, IFC, LLB, and BDF had 3 yr with annual precipitation well above average and 1 yr of annual precipitation well below the average annual total. However, WHC had 2 yr of annual precipitation above and 2 yr below the 30-yr average.

Table 2.3. Weather stations in close proximity to Indianfarm Creek (IFC), Whelp Creek (WHC), Battersea Drain Field (BDF), and Lower Little Bow River Field (LLB).

Site	Weather station name	Data provider[z]
IFC	Pincher Creek AUT	EC
	Brocket AGDM	ACIS
WHC	Lacombe CDA 2	EC
	Prentiss	ACIS
BDF and LLB	Iron Springs IMCIN	EC
	Picture Butte West	ACIS

[z] EC = Environmenta Canada; ACIS = AgroClimatic Information Service.

Table 2.4. Annual precipitation[z] at the Indianfarm Creek (IFC) Watershed, Whelp Creek (WHC) Sub-watershed, Lower Little Bow River Field (LLB), and Battersea Drain Field sites from 2007 to 2010.

	IFC	WHC	LLB and BDF
Year	---------------------------	(mm)	---------------------------
30-yr average[y]	515	446	365
2007	327	517	255
2008	644	280	409
2009	544	295	387
2010	679	628	410

[z] Precipitation values are from the nearest Environment Canada (2011) weather station.
[y] 30-yr averages are for 1971 to 2000 (Environment Canada 2011).

2.3.2 Soil Physical Characteristics

The soil-physical parameters have a major impact on predicted movement of water and air within a soil profile and on predicted water balance within a HRU. Table 2.5 lists the soil physical properties and describes the data sources and methods that were used to calculate these values for SWAT and APEX.

Table 2.5. Sources of soil-physical properties for provincial watersheds.

Parameter	Definition	Data source for Alberta
HYDGRP	Soil Hydrologic Group - part of United States Soil Conservation Service Curve Number (SCS-CN) method that describes relationship between rainfall and runoff under given soil and land cover conditions. The SCS method identifies four hydrological soil groups (A, B, C, D) based on soil permeability.	The grouping was assumed based on the saturated hydraulic conductivity (K) of most restrictive layer to a depth of 1.0 m using the following grouping criteria: A for K > 254 mm h^{-1}, B for K ranging between 84 and 254 mm h^{-1}, C for K ranging between 8.4 and 84 mm h^{-1}, and D for K < 8.4 mm h^{-1}.
Sol_ZMX	Maximum rooting depth of soil profile	Assumed the same as the entire depth of soil profile
ANION_EXCL	Fraction of porosity from which anions are excluded	Assumed model default 0.50
SOL_CRK	Potential crack volume of the soil profile	Assumed model default 0.50 m^3 m^{-3}
TEXTURE	Texture of soil layer	AGRASID database[z]
SOL_Z	Depth from soil surface to bottom of layer	AGRASID database
SOL_BD	Moist bulk density	AGRASID soil texture data and Saxton and Willey (2006) equations[y]
SOL_AWC	Available water capacity (AWC) of the soil layer	AWC = FC – WP[x]
FC	Water content at field capacity	AGRASID soil texture data and Saxton and Willey (2006) equations
WP	Water content at permanent wilting point	AGRASID soil texture data and Saxton and Willey (2006) equations
SOL_K	Saturated hydraulic conductivity	AGRASID soil texture data and Saxton and Willey (2006) equations
SOL_CBN	Organic carbon content	AGRASID database
CLAY	Clay content	AGRASID database
SILT	Silt content	AGRASID database
SAND	Sand content	AGRASID database
ROCK	Rock fragment content	AGRASID database
SOL_ALB	Moist soil albedo	SOL_ALB = $(0.7/ (\text{Exp}(0.5596*\text{OM})))^2$ Where: OM = SOL_CBN *1.724
USLE_K	USLE soil erodibility (K) factor[w]	Williams (1995) equations

[z] AGRASID = Agricultural Region of Alberta Soil Inventory Database (Alberta Soil Information Centre 2001).
[y] The performance of the Saxton and Willey (2006) equations was evaluated by comparing the predicted SOL_BD, FC, and WP values with the measured values (no included in this report). The comparison of 55 soil records obtain from 40 different soil quality benchmark sites yielded r^2 of 0.66, 0.60, and 0.78 for SOL_BD, FC, and WP, respectively.
[x] FC = field capacity moisture content; WP = wilting point moisture content.
[w] USLE = Universal Soil Loss Equation.

2.3.3 Soil Chemical Characteristics

To initiate simulations, SWAT and APEX require initial concentrations of NO_3-N, organic N (ON), water soluble P (WSP), and organic P (OP) for all soil layers. Generally, WSP is not readily available because soil-test P (STP) is more commonly measured. In the BMP Project, soil samples were collected from the 0- to 15-cm depth on selected sites to measure NO_3-N, ammonium nitrogen (NH_4-N), and STP concentrations. The STP content was tested using the Modified Kelowna (MK) method (Qian et al. 1991). More detailed information on soil sampling is available in ARD (2014). Wright et al. (2003) showed that there is a linear correlation ($y = 0.84x-16$, $r^2 = 0.99$) between the MK and Mehlich 3 methods for STP. To estimate the WSP values, first the MK STP values were converted to Mehlich 3 STP values, using the equation from Wright et al. (2003). Then an algorithm described by McFarland (2006) was used to estimate WSP based on the Mehlich 3 STP values.

2.3.4 Measured Water Quantity and Quality

As of December 2010, 4 yr of flow and water quality data were available for the IFC Watershed and the LLB and BDF sites, and 3 yr for the WHC Sub-watershed. These data have been discussed in more detail in ARD (2014). The available data from these watersheds were used for the initial SWAPP (SWAT and APEX) testing and calibration processes.

It is important to note that in contrast to the water monitoring data, SWAPP separates P into orthophosphate (PO_4-P) and OP fractions, and N into NO_3-N and ON fractions. The PO_4-P and NO_3-N fractions were considered water soluble; whereas, the OP and ON fractions were considered sediment bond. In SWAPP calibration, the PO_4-P and OP fractions were assumed to be equivalent to total dissolved P (TDP) and particulate (PP) fractions, respectively, as reported in ARD (2014). In addition, for total phosphorus (TP) and total nitrogen (TN) it was assumed that:

$$TP = PO_4\text{-}P + OP$$
$$TN = NO_3\text{-}N + ON + \text{nitrite N } (NO_2\text{-}N) + \text{ammonia N } (NH_3\text{-}N)$$

To prepare for calibrating sediment and nutrient losses for IFC and WHC, an initial analysis of the relationships between stream daily discharge and nutrient and sediment concentrations was conducted. Strong relationships ($P < 0.005$) existed between stream discharge and ON, OP, PO_4-P, and total suspended solids (TSS) at the main stream sites (Stations 1, 5, and 11) in IFC (Table 2.6). However, WHC only showed a strong ($P < 0.005$) correlation with PO_4-P and a weaker correlation with ON ($P < 0.05$) at the outlet (Station 301). The field sites generally had weaker and often insignificant correlations relative to the main stream sites in IFC. Whereas, in WHC, field Station 314 flow had relatively strong correlations with NO_2-N, NH_3-N, ON, and OP. At field Station 319, nutrient and sediment concentrations were inversely related to discharge, and this may have resulted from groundwater influences and a relatively high water table. The lack of correlation between nutrient or sediment concentration with stream discharge suggests that other factors may control the export of sediment and nutrients.

Table 2.6. Spearman rank correlation (r_s) results for nutrient and sediment concentrations correlated with stream discharge at Indianfarm Creek Watershed (2007 to 2009) and Whelp Creek Sub -watershed (2008 to 2009).

Station	n[z]	NO_3-N[y]	NO_2-N	NH_3-N	ON	PO_4-P	OP	TSS
				Indianfarm Creek Watershed[x]				
1	65	0.06 ns	-0.03 ns	-0.07 ns	0.40 ****	0.38 ****	0.56 ****	0.58 ****
4	21	-0.07 ns	0.24 ns	0.25 ns	-0.01 ns	0.19 ns	0.49 **	0.48 **
5	61	0.07 ns	-0.03 ns	-0.08 ns	0.57 ****	0.39 ****	0.56 ****	0.54 ****
9	12	0.24 ns	0.45 ns	0.74 **	0.64 *	0.74 **	0.65 **	0.30 ns
11	52	0.27 *	-0.11 ns	0.01 ns	0.59 ****	0.52 ****	0.60 ****	0.71 ****
15	8	0.49 ns	0.30 ns	0.07 ns	0.37 ns	0.40 ns	0.06 ns	0.09 ns
18	45	0.47 ****	-0.06 ns	0.17 ns	0.27 *	0.05 ns	0.16 ns	0.32 **
21	17	-0.02 ns	-0.09 ns	0.59 **	-0.24 ns	-0.27 ns	-0.15 ns	0.12 ns
				Whelp Creek Sub-watershed[x]				
301	36	-0.02 ns	-0.07 ns	-0.12 ns	0.31 *	0.79 ****	0.22 ns	0.08 ns
307	8	0.44 ns	0.56 ns	0.26 ns	0.41 ns	0.10 ns	0.81 ns	0.47 ns
309	13	-0.09 ns	0.12 ns	-0.65 **	-0.19 ns	0.03 ns	0.31 ns	0.18 ns
311	24	-0.23 ns	0.01 ns	0.42 *	0.53 ***	0.21 ns	0.21 ns	-0.04 ns
314	28	-0.28 ns	0.48 ***	0.41 **	0.50 ***	0.28 ns	0.45 **	0.08 ns
318	8	0.54 ns	-0.05 ns	0.10 ns	0.13 ns	0.13 ns	0.29 ns	0.46 ns
319	31	-0.18 ns	-0.32 *	-0.13 ns	-0.43 **	-0.17 ns	-0.45 ***	-0.41 **
324	5	0.40 ns	0.00 ns	0.00 ns	0.90 ns	0.90 ns	0.60 ns	-0.36 ns

[z] Number of observations.
[y] NO_3-N = nitrate nitrogen, NO_2-N = nitrite nitrogen, NH_3-N = ammonia nitrogen, ON = organic nitrogen, PO_4-P = orthophosphorus, OP = organic phosphorus, TSS = total suspended solids. Organic N = total Kjeldahl – NH_3-N. Organic P = TP – PO_4-P. Organic P values may be slightly overestimated because particulate inorgan ic P was not measured; however, this fraction was assumed to be negligible.
[x] Correlation significance is denoted * ($P < 0.05$), ** ($P < 0.025$), *** ($P < 0.01$), **** ($P < 0.005$), and ns (not significant).

2.3.5 Livestock Inventory

Livestock inventories were used to estimate of the amount of manure applied to agricultural lands in IFC and WHC. An estimate of the number of livestock in IFC was obtained via the aerial survey conducted on March 5, 2009 (ARD 2014). In WHC, a livestock inventory estimate was determined from the 2007-2008 land-use and economics survey (ARD 2014). The livestock inventories were continuously updated through field observations and updates from producers. The total number of cows and calves in IFC was estimated at 10,725, with approximately 8000 cattle confined in two feedlots and about 2725 on pasture (Table 2.7). In WHC, there were approximately 2159 cows and 481 calves, with approximately 1879 cows confined in dairy operations and 280 on pasture. In addition to the livestock estimate in WHC, there is a small feedlot with approximately 400 cattle (capacity of 1500) located just outside the boundary of the watershed. The majority of the manure produced in this feedlot was spread in the northern portion of WHC (Sub-basin 18). It is important to note that cattle were essentially the only type of livestock in the IFC and WHC watersheds.

Table 2.7. Livestock inventory estimates by sub-basin for the Indianfarm Creek Watershed in 2009 and the Whelp Creek Sub-watershed in 2007 and 2008.

Indianfarm Creek Watershed		Whelp Creek Sub-watershed		
Sub-basin	Cows and calves	Sub-basin	Cows	Calves
1	160	1	0	0
2	0	2	0	0
3	0	3	110	20
4	50	4	0	0
5	325	5	0	0
6	0	6	0	0
7	50	7	394	105
8	0	8	0	0
9	0	9	0	0
10	0	10	0	0
11	0	11	0	0
12	0	12	0	0
13	35	13	0	0
14	4,000	14	76	72
15	0	15	0	0
16	0	16	336	68
17	0	17	220	60
18	200	18	923	61
19	0	19	0	0
20	4,075	20	0	0
21	1,125	21	0	0
22	70	22	100	95
23	0			
24	0			
25	560			
26	75			
27	0			
Total:	10,725	Total:	2159	481

2.4 Gaps, Assumptions, and Limitations in the Existing Database

Osei et al. (2009) outlined in a protocol document a comprehensive list of the data requirements for using computer modelling systems, particularly CEEOT, to evaluate the economic and environmental impacts of BMPs. The protocol document also discussed the 2008 data gaps and how to address these gaps. For the most part, data items indicated by Osei et al. (2009) as a minimum requirement were available for CEEOT simulations. However, data acquisition efforts were ongoing and additional data were added during the project to meet each of the data requirements (Section 3). In addition to this effort, the following assumptions were made while the SWAPP calibrations were conducted.

2.4.1 Soil Data

Soil samples were collected at the field scale in the watersheds where the BMPs were implemented (ARD 2014). The soil characterization data showed that soil texture varied among sampling locations on each farm field. However, the modelling soil input data did not capture this variability due to the fact that delineation of soil texture distribution at very fine-scale was beyond the scope of the BMP Project. Therefore, the modelling of soil input data (distribution of soil texture) was generalized according to the AGRASID information.

2.4.2 Land Management Data

As mentioned above, the land management data were collected each year by recording land cover distribution and by annual interviews about farming activities with the producers with BMP sites on their land. However, this type of information was not available for the majority of farm polygons within each watershed. Collecting such detailed information was beyond the scope of the BMP Project. Therefore, for modelling purposes, the detailed field-level information was extrapolated to the nearby fields where the land cover was similar. With this approach, it was possible that the farm management data extrapolated to adjacent polygons may not have captured the actual farm practices such as manure and fertilize application rates, timing and intensity of the farm operations, and livestock stocking rates and grazing management.

2.4.3 Precipitation Data

The precipitation data collected at the IFC and WHC weather stations were variable among rain gauges within each watershed. In modelling, it was assumed that the observed data from four IFC and two WHC stations was sufficient to capture a distribution of rainfall amounts within each watershed. In addition, it was assumed that the snow data acquired from nearby Pincher Creek, Lacombe, and Lethbridge weather stations were acceptable for the study watersheds.

2.4.4 Pond, Wetland, and Reservoir Data

Three types of impoundment parameter inputs were estimated for SWAPP: the fraction of sub-basin area that drains into a water body (contributing area coefficient), the surface area, and the impoundment storage capacity. The contributing area coefficients were estimated based on visual interpretation of the spatial distribution of impoundments within each sub-basin (Table 2.8). The coefficient value ranged from 0.02 to 1.00 and its value increased with increasing proximity to the sub-basin outlet and the main channel. The storage capacity of impoundments was initially estimated by assuming the maximum average depths were 0.2 m for ponds, 0.3 m for wetlands, and 3.6 m for dugouts. However, these assumptions over simplified the storage capacities of the impoundments, and the final storage values were estimated during the auto-calibration of SWAT (Section 4).

In the IFC Watershed, the ponds were often dugouts, and the wetlands were natural areas that had very small water storage capacities relative to ponds. As a result, the wetland storage characteristics were combined with the pond characteristics, and they were entered into the SWAT model as one type of impoundment. Also, it was estimated that the ponds and wetlands accounted for 17.7 ha of the IFC area and they had about 403,000 m^3 store capacity (Table 2.8). For the WHC Sub-watershed, it was estimated that ponds occupied an area of about 14.2 ha with a storage capacity of 218,000 m^3, and wetlands occupied an area of about 175.6 ha, with a storage capacity of 389,000 m^3.

Table 2.8. Estimated impoundment parameters for Indianfarm Creek (IFC) and Whelp Creek (WHC) watersheds.

Sub-basin	Contributing area coefficient[z]	Surface area (ha)	Storage capacity ($\times 10^4$ m^3)	Sub-basin	Contributing area coefficient[z]	Surface area (ha)	Storage capacity ($\times 10^4$ m^3)
IFC ponds and wetlands				IFC reservoirs[y]			
1	0.02	0.30	1.20	2	1	0.75	1.9
3	0.85	0.24	0.96	12	1	1.43	2.8
4	0.95	1.00	0.30	15	1	0.5	1.1
5	0.08	1.83	7.32	20	1	14.2	60
6	0.79	0.50	0.10	27	1	7.2	29
9	0.95	2.00	0.40	Total		24.1	94.8
14	0.08	2.09	8.36				
16	0.45	2.50	0.40				
17	0.01	1.05	0.60				
18	0.61	1.20	0.80				
20	0.28	1.76	7.04				
22	0.01	0.13	0.52				
23	0.90	1.62	6.48				
24	0.15	0.51	2.04				
25	0.03	0.39	1.56				
26	0.08	0.56	2.24				
Total		17.7	40.3				
WHC ponds				WHC wetlands			
1	0.82	0.34	2.88	1	0.73	16.85	4.58
2	0.90	0.70	0.40	7	0.85	30.08	9.94
3	0.10	0.45	0.24	8	0.60	0.37	0.07
4	0.17	0.62	0.04	9	0.72	34.13	9.78
5	0.79	1.59	0.51	11	0.20	1.46	0.20
7	0.76	0.65	5.15	14	0.20	43.16	5.86
9	0.69	0.69	2.07	16	0.17	9.80	1.36
10	0.75	0.24	0.02	17	0.04	7.31	1.11
11	0.92	1.66	0.56	18	0.23	22.99	4.63
12	0.94	0.60	0.14	19	0.02	0.32	0.01
14	0.29	4.42	6.17	20	0.03	1.29	0.19
16	0.13	0.30	0.72	22	0.02	7.83	1.21
18	0.33	1.56	2.19	Total		175.6	38.9
19	0.04	0.09	0.01	WHC reservoirs[y]			
20	0.02	0.17	0.34	7	1	1.60	0.40
22	0.02	0.12	0.37	9	1	0.45	1.10
Total		14.2	21.8	12	1	0.75	0.18
				14	1	44.00	43.00
				18	1	0.69	1.00
				Total		47.5	45.7

[z] Proportion of sub-basin area that drains into a pond, wetland, or reservoir.
[y] Parameters were estimated at the emergency spillway level.

The storage parameters of the constructed reservoirs were based on the available dam design specifications. The parameters of the remaining reservoirs (dugouts and natural depressions) were estimated based on the assumptions mentioned above.

In SWAT simulations, the user has the option of entering the surface area and water storage volume at the principal and emergency spillway water levels for each impoundment. The former level relates to full storage supply or flood control level and the latter level relates to the emergency flood control level. For nearly all of the impoundments, except for the constructed reservoirs (IFC Sub-basins 20 and 27, and WHC Sub-basin 14), it was assumed that the water surface areas and the water storage volumes were the same at the principal and at the emergency spillway water levels.

3 FEM DATA DEVELOPMENT AND CALIBRATION

3.1 Development of Representative Farms

Representative farms were established for the two watersheds and the LLB site to serve as the basis for the FEM simulations and economic impact analysis. The representative farm structures were based primarily on information obtained through the producer surveys. Based on the surveys, 13 representative farms were established for the IFC Watershed, 27 representative farms for the WHC Sub-watershed, and one representative farm for the LLB site (Table 3.1). The representative farm for the BDF field site was not completed because this site was dropped from the CEEOT calibration, as explained in Section 4.1. The survey farms were not an exact replication of the farms in each watershed, but did reflect the diversity of operations in the two watersheds.

The model provides the capability to include as much detailed farm-level information as required. The information used in defining each of the representative farms in FEM included the data categories in Table 3.2. The check marks in the table indicate the primary source of the data. For example, the field operations information was drawn primarily from the surveys in order to reflect the actual management practices in the watersheds.

Table 3.1. Representative farm types in the Indianfarm Creek Watershed (IFC), Whelp Creek Sub-watershed (WHC), and Lower Little Bow River Field (LLB).

Farm type	IFC	WHC	LLB
Cow-calf	1		
Backgounding/finishing	2	1	
Cow-calf/backgounding/finishing	9	7	
Dairy		7	
Dairy and cattle	1		
Swine		1	
Horse		1	
Crop		10	
Irrigated crop			1

Table 3.2. Primary and secondary data sources.[z]

Data categories	Field surveys	ARD databases[y]	Model defaults
Land area farmed – owned / leased	✓	*	
Cropping systems	✓	*	
Field operations	✓	*	
Crop yields	✓	*	
Livestock inventory	✓	*	
Equipment inventory	✓		✓
Farm structures and facilities		✓	✓
Farm lending and borrowing terms			✓
Farm input and output prices		✓	*

[z] ✓ = primary data source, * = secondary data source.
[y] ARD = Alberta Agriculture and Rural Development.

In most cases, the data were supplemented by other sources, as indicated by an asterisk in Table 3.2. For instance, the proportion of owned land was usually provided in the farm surveys. However, when this was not available, regional figures were obtained from ARD databases.

In two categories, there were two primary sources. For example, farmers that completed the long survey provided an inventory of farm machinery and identified the equipment used on each field operation. The short survey did not ask for information on equipment inventories, and consequently, the FEM automatically assigned equipment from the internal default equipment table to complete the representative farm structure. Also, detailed information on farm structures and facilities were available from ARD databases for dairy farms, while other farm types were assigned general estimates for total value of farm structures.

The field operations or management practices identified in the 2007 farm surveys (long and short surveys) included all aspects of cropping and livestock operations. A summary of three management practices that could impact water quality in the two watersheds and the field-scale site are shown in Table 3.3. For example, of the 13 farms surveyed in IFC, twelve farms grazed cattle, and that occurred on 89 of the 104 fields covered in the farm surveys. However, only three farms applied manure to fields, and that occurred on only four fields in total. It is important to note that the areas shown in the table reflect land areas operated by the farm and not necessarily the size of the drainage area simulated in FEM.

3.2 Farm Data Sources

Most of the farm management data were obtained through producer surveys. These data included field operations, crop yields, and livestock inventories, sales and purchases. Price data for most farm inputs and outputs were collected by ARD staff for the FEM simulations. Specific data sources are shown in Table 3.4.

Table 3.3. Summary of selected management practices identified in the 2007 farm surveys.

	Survey farms in the FEM	Summary of selected management practices: Grazing	Manure applied	Fertilizer applied
		Indianfarm Creek Watershed		
Farms	13	12	3	8
Fields	104	89	4	35
Area (ha)	5806	5100	300	3033
Application rate (Mg ha^{-1})	-	-	60.2	-
		Whelp Creek Sub-watershed		
Farms	27	11	11	19
Fields	116	23	35	50
Area (ha)	2726	265	970	599
Application rate (Mg ha^{-1})	-	-	58.3	-
		Lower Little Bow River Field		
Farms	1	-	1	1
Fields	2	-	2	2
Area (ha)	305	-	305	305
Application rate (Mg ha^{-1})	-	-	85.0	-

Table 3.4. Farm price datasources.

Data	Source[z]
Regional crop area distribution	ARD, Statistics Canada
Farm input prices	ARD
Farm product prices– crop and forage	ARD, AFSC, CWB
Crop yields	AFSC, Statistics Canada, AGC, ARD
Cost and returns estimates– crop, forage, livestock	ARD (AgriProfit$)
Crop agronomic requirements	ARD
Crop nutrient contents	USDA, NRC
Livestock nutrient requirements	NRC
Ammonia volatilization losses by manure application type	ARD
Manure production characteristics	ASABE, ARD

[z] AFSC = Alberta Financial Services Corporation, AGC = Alberta Grain Commission, ARD = Alberta Agriculture and Rural Development, ASABE = American Society of Agricultural and Biological Engineers, CWB = Canadian Wheat Board, NRC = US National Research Council, USDA = United States Department of Agriculture.

3.3 Management Data Input

As mentioned in Section 2.1.2, management data from the 2007 survey were assembled first into a tabulate format and then Visual Basic scripts were used to convert them into input files for the CEEOT modelling system. These input files can be imported directly by FEM. However, FEM also is able to obtain some of this management data through interfacing with SWAT.

During simulation of the baseline and alternative scenarios, any changes in management practices at the farm level for a given scenario (e.g., changes in manure application rates and timing) were conveyed to FEM through the CEEOT interface program. The CEEOT interface also conveyed the results obtained from SWAT and APEX simulations (e.g., sediment and nutrient losses) to FEM as well as to where FEM evaluated the economic impacts of changes in environmental factors (e.g., sediment and nutrient losses).

3.4 Gaps and Limitations in the Existing Database

The representative farms developed for the economic evaluation through the FEM were based directly on farm surveys. In some cases, the surveys were missing information about the size or composition of the farm, or the information did not reflect normal farm conditions. These deficiencies can negatively affect the estimates of total farm net revenue. However, this may not affect the impact analysis of the policy scenarios since the change in net farm income resulting from the new management practice is the main focus. Nevertheless, to improve the assessments of baseline net farm incomes, supplemental information was added to the FEM farms. Examples are:

1. Some of the farms had farm property outside the study area, for which no farm management information was collected (i.e., field operations and crop production). Consequently, the machinery capital equipment costs were originally allocated in FEM to a small land area. This resulted in excessively high costs per hectare, and unrealistically low net revenue estimates. To resolve this, several representative farms required the inclusion of additional hypothetical fields to better reflect the actual area farmed as indicated in the surveys. Crop operations data for these additional fields were based on other fields in the farm, or from similar farms within the watershed.

2. Some farm managers shared equipment with other farm managers. Adjustments were needed to ensure the machinery capital costs on a per hectare basis were realistic.

3. Low yields were periodically recorded due to low rainfall levels during either the pre- or post-BMP years of the project. In some cases, this would have adversely impacted the results of the policy scenario analysis. Specifically, the economic analysis results of changes in net farm income would reflect weather patterns more so than the BMP implementation. Consequently, these yields were adjusted to reflect more normal weather conditions in order to better reflect the economic impact of the BMP scenario. It is important to note that yield adjustments were not made for the APEX and SWAT runs because yield is not an input into those models, but rather an output from the models.

4. Many of the policy scenarios involved the development of setbacks or buffer zones. These setbacks often required a change in manure or fertilizer applications rates. This in turn would likely have resulted in a change in crop yields. Since resources were not available to measure or obtain these changes in yield, assumptions were made. Essentially, the yields on setback areas were reduced in proportion to the reduction in nutrient applications since supplementary nutrient applications were not made on those fields. The accuracy of the assumed changes could have affected the estimated economic impact of the scenario analysis.

3.5 FEM Calibration Results and Discussion

The Farm-level Economic Model was calibrated to reflect the economic conditions of farms in Alberta. For FEM calibration, the average annual output from FEM was compared with farm cost and returns data for Alberta. In some cases, prices and other cost components were adjusted to better reflect Alberta conditions.

The calibration primarily entailed adjusting model input parameters to ensure that costs of field operations were similar to summaries reported in custom rate surveys applicable to Alberta. The model was also calibrated to ensure that cost components of various livestock enterprises were also in line with annual published estimates maintained by ARD economists. Simple comparisons were made to determine in each case whether the fixed and variable cost components and total costs reported by FEM were reasonably in line with the published estimates (ARD 2007a, 2007b, 2009). In general, output from FEM on costs of field operations were reasonably in line with the published estimates and little adjustment in model coefficients was necessary to bring the model output in line with the observed data. On the other hand, cost components of livestock enterprises were adjusted more substantially to bring the FEM output on livestock operations in line with published data on costs and returns for dairy, beef, and hog operations.

4 SWAPP CALIBRATION

4.1 Calibration Procedure

The SWAPP stream flow calibrations for IFC and WHC were initiated in 2009 and continued in 2010 and 2011. Calibrations were also started for the single monitoring station at LLB and for three edge-of-field monitoring stations at the BDF site in 2009, and continued only for LLB in 2010 and 2011. In 2010, the BDF site was excluded from subsequent modelling due to very poor flow calibration results and difficulties in obtaining satisfying results in subsequent model runs. These difficulties were related to very low average monthly flow rates and high variability of runoff among monitoring stations under the similar irrigation amounts.

Model calibrations were conducted by running SWAT and APEX within SWAPP on a daily basis from 2000 to 2010 for IFC and LLB, and from 2002 to 2010 for WHC. The first 7 yr for IFC (2000 to 2006) and 6 yr for WHC (2002 to 2007) simulations were considered as an equilibration (warm-up) period for the model. This period was deemed necessary for soil conditions and other biophysical properties to reach levels reflective of the management practices being simulated. Accordingly, the first several years of model output were not included in calibration results or output of model simulations for the scenarios. With few exceptions, the last 4 yr (2007 to 2010) of simulations were used for assessing model performance for IFC, and the last 3 yr (2008 to 2010) were used for LLB and WHC. This assessment was carried using a statistical procedure (Sub-section 4.2). For the LLB site, 2007 was not used in the calibration process because the 2007 irrigation volumes were not measured at the site.

In the IFC Watershed, nine sub-basins were selected for the SWAPP calibration based on the availability of large amount of field data collected at these sites (Figures 2.1d and Table 2.1). Six of the sub-basins were outlets of BMP sites (Stations 2, 4, 10, 15, 18, and 21). Two were along the main stream (Stations 5 and 11) and one was at the watershed outlet (Station 1). The 2007 to 2010 observed maximum average monthly flow was 0.092 $m^3 s^{-1}$ at Station 2 (primary tributary) and 5.0 $m^3 s^{-1}$ at Station 1 (watershed outlet).

For the WHC Sub-watershed, nine of the 22 sub-basins were also selected for the SWAPP calibrations based also on the availability of large amount of field data collected at these sites (Figures 2.2d and Table 2.2). In the selected sub-basins, six sub-basins were the outlets of BMP sites (Stations 307, 309, 314, 318, 319, and 324) and one sub-basin (Station 311) was within the North Field BMP site. One main tributary was in Sub-basin 18 (Station 303) and the WHC outlet was in Sub-basin 20 (Station 301). Observed maximum average monthly flows were 0.008 $m^3 s^{-1}$ at Station 319 and 0.188 $m^3 s^{-1}$ at Station 301 from 2008 to 2010.

For the LLB site, the calibration was conducted for the site outlet (Station 101; Figure 2.5), since there was no flow measurement available at a sub-basin scale. The observed maximum average monthly flow was 0.003 $m^3 s^{-1}$ from 2008 to 2010.

To calibrate the model in this study, the pre- and post-BMP management conditions were included. The BMPs were actually implemented at different times among the BMP sites (Figure 1.2), and the model input land management data captured the variability of field operations and timing of BMP implementation. The SWAPP calibration was conducted based on the modelling procedures and instructions provided in the user manuals of Steglich and Williams (2008) and Waidler et al. (2011). Ultimately, the calibration process resulted in establishing values for a set of parameters and assumptions that represented the environmental baseline or calibration baseline scenario.

To obtain adequate model performance without unduly time-consuming calibration procedure, a two-step procedure was used in calibration. In the first step, calibration was performed using only SWAT. There were two reasons for this: First, an auto-calibration procedure is available in SWAT, but not in APEX. This auto-calibration routine allows improvements to the SWAT model performance with little effort. Second, when calibrating with two models it can be very difficult to determine the reasons for changes in model performance. Thus, it is often necessary to resort to a stepwise calibration process when more than one model is involved. In this case the natural recourse is to start with SWAT and use its auto-calibration routine to establish basic parameters for the watershed that provide reasonable performance. In the second step, APEX calibration was performed in concert with the previously calibrated SWAT model to arrive at desired parameters for simulations.

The SWAT auto-calibration was conducted using a computer program called SWAT-CUP2 (Abbaspour 2008). The program includes four sub-programs: Sequential Uncertainty Fitting algorithm (SUFI-2), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol), and a Bayesian framework implemented using a Markov chain Monte Carlo (MCMC) technique. In this project, the SUFI-2 sub-program was selected because it uses very efficient and reliable optimization algorithms that allow for the completion of calibration and uncertainty analyses in a reasonable timeframe (Setegn et al. 2009).

Once the SWAT auto-comparison showed a reasonable agreement between monthly simulated and measured flow values, the majority of SWAT input files were exported into SWAPP for further manual calibrations of the SWAT and APEX models. Within SWAPP, the majority of the land-use categories (i.e., subareas) were assigned to APEX. The SWAT model was primarily used to route the APEX predicted flow, TSS losses, and nutrient losses through existing stream channels and reservoirs to the watershed outlet. Based on prior experience in other watersheds, the project team expected improved results with the entire SWAPP system than with the SWAT model alone (Saleh and Gallego 2007; Saleh et al. 2007; Osei et al. 2008a). In the current modelling study, nutrient and sediment losses in surface water were expressed as loads, or more specifically as export coefficients (kg ha^{-1} or Mg ha^{-1}).

4.2 Evaluation Methods

The mean monthly flow rates, sediment losses, and nutrients losses obtained from the calibrated SWAT and SWAPP were compared with measured values (2007 to 2010) from the two watersheds and the LLB site to assess model performance. Although SWAT and APEX can produce daily, monthly, and annual results, it was decided to use the monthly values based on a number of difficulties associated with daily measurements and the unreliability of model results under very low runoff conditions. In addition, since the model was used to compare the BMP scenarios using the modelled annual average results obtained from 30-yr periods, the monthly calibration was sufficient.

Two statistical methods were used to evaluate the performance of the SWAT and SWAPP models. The first statistical method used the correlation of determination (R^2) to evaluate the precision of the regression models to predict flows, sediment losses, and nutrient losses. The R^2 is the proportion of total variation in the observed data that can be accounted for by a linear equation using the predicted values.

The second method of evaluating model predictions is the Nash and Sutcliffe coefficient (Nash and Sutcliffe 1970). This method measures how well the distribution of predicted values corresponds to the distribution of values using the following equation:

$$E = 1 - \frac{\sum_{i=1}^{n} \left(Oi - Pi\right)^2}{\sum_{i=1}^{n} \left(Oi - \overline{O}\right)^2} \qquad \text{Equation 4.1}$$

where: E = Nash and Sutcliffe coefficient
n = the number of observations
O_i = observed mean monthly values ($m^3\ s^{-1}$)
P_i = predicted mean monthly values ($m^3\ s^{-1}$)
$\bar{O}$ = mean O_i for the entire observation period ($m^3\ s^{-1}$)

An E value of one indicates perfect agreement between the average annual observed and model predicted values. An E value of zero indicates that the predicted values are no better than the observed mean. Furthermore, when E is less than zero, it indicates that the model predictions are worse than using the observed mean. In this study, an E value of 0.6 or higher was considered indicative of a satisfactory calibration; however, it was expected that lower E values could be obtained based on the very low magnitude of flow, TSS losses, and nutrient losses at the field scale.

4.3 Setting Values of Parameters used in SWAPP Calibration

4.3.1 Setting Values for SWAT Parameters

For the IFC Watershed SWAT auto-calibration, 60 simulations were selected for the input parameter sensitivity analysis. Based on these results, the 17 most significant of these parameters were selected for further auto-calibration efforts (Table 4.1). These included parameters related to snowmelt, water balance, and surface runoff. The values of these parameters were allowed to vary during the auto-calibration process, while the other SWAT parameters not being calibrated were held constant. Only the CN2 parameter in the .mgt files, the CH_K2 parameter in the .rte files, and the SOL_ALB parameter in the .sol files (Table 4.2) were allowed to vary independently among sub-basins within the IFC Watershed. All other parameters were held constant for all IFC sub-basins.

For the WHC Sub-watershed SWAT auto-calibration, more than 500 simulations were initially conducted for the input parameter sensitivity analysis. Based on these simulations, 37 parameters were entered into SUFI-2 from the SWAT input files (Tables 4.1 and 4.2). These parameters were considered to be sensitive for the water balance and magnitude of surface runoff. The 37 parameter values were allowed to vary in each simulation while the other SWAT parameters were held constant.

Table 4.1 shows the initial minimum and maximum values and final values for 17 parameters calibrated within SUFI-2 with a “v__” code. The “v__” code in front of each parameter indicates that the initial parameter value was replaced by a given value. Table 4.2 shows the minimum and maximum initial and final values for an additional 20 parameters calibrated within SUFI-2 with “r__ and “v__” codes. The “r__” code in front of each parameter means that the initial parameter value was multiplied by one plus a given value. The LLB site was calibrated manually, and therefore, only the SWAT parameters in Table 4.1 were provided.

The initial range of values of the “v__” code parameters were set to be equal to the maximum values recommended in the SWAT user manual (Neitsch et al. 2005). Whereas, the initial values of the “r__” code parameters were estimated using the above mentioned datasets. Since the estimated initial values had high spatial variability, they were allowed to vary in auto-calibration within ±10% of the initial values. In addition, the value changes of “.bsn” parameters were applied uniformly to all sub-basins within the WHC Sub-watershed. The values of the remaining parameters shown in Tables 4.1 and 4.2 (.hru, .gw, .pnd, .mgt, .rte, and .sol) were allowed to vary independently among sub-basins within the WHC Sub-watershed.

Table 4.1. Range of values for selected SWAT parameters for Indianfarm Creek Watershed (IFC), Whelp Creek Sub-watershed (WHC), and Lower Little Bow River Field (LLB).

Selected parameters		Range of values				
		Initial		Final		
Name in SWAT [z]	Description	Min.	Max.	IFC	WHC	LLB
v__SFTMP.bsn	Snowfall temperature (ºC)	-5	5	0.60	0.61	0.60
v__SMTMP.bsn	Snowmelt base temperature (ºC)	-5	5	2.72	2.70	2.78
v__SMFMX.bsn	Melt factor for snow on June 21 (mm water/ºC-day)	0	10	4.95	5.98	4.95
v__SMFMN.bsn	Melt factor for snow on December 21 (mm water/ºC-day)	0	10	2.48	2.54	2.48
v__TIMP.bsn	Snow pack temperature lag factor	0.01	1	0.07	0.10	0.07
v__SNOCOVMX.bsn	Minimum snow water content that corresponds to 100% snow cover, SNO100, (mm water)	0	50	37	30	30
v__SNO50COV.bsn	Fraction of snow volume represented by SNOCOVMX that corresponds to 50% snow cover	0.01	0.99	0.16	0.28	0.16
v__SURLAG.bsn	Surface runoff lag coefficient	1	12	1	1	1
v__ESCO.bsn	Soil evaporation compensation factor	0.01	1	0.67	0.90	0.87
v__EPCO.bsn	Plant uptake compensation factor	0.01	1	0.89	0.30	0.69
v__CANMX.hru	Maximum canopy storage (mm water)	0	100	9	4	4
v__GW_REVAP.gw	Groundwater “revap” coefficient	0.02	0.2	0.03	0.02	0.02
v__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm water)	0	5000	16	2	0
v__ALPHA_BF.gw	Base flow alpha factor (days)	0	1	0.36	0.22	0.05
v__GW_DELAY.gw	Groundwater delay time (days)	0	500	1	1	31
v__REVAPMN.gw	Threshold depth of water in the shallow aquifer for “revap” or percolation to the deep aquifer to occur (mm water)	0	500	17	17	1
v__RCHRG_DP.gw	Deep aquifer percolation fraction	0	1	0.08	0.02	0.05

[z] Abbreviations for SWAT input files extensions: .bsn = basin, .hru = hydrologic response unit, . gw = groundwater.

During the auto-calibration, SUFI-2 adjusted the value of the IFC and WHC parameters based on the provided initial range of values while holding the others fixed. After completing all simulations defined in the iteration, SUFI-2 provided suggestions for a new range of values for those parameters that would most likely improve model predictions. In total, five iterations were completed for the WHC Sub-watershed, and this included more than 2500 SWAT simulations. At that point, the auto-calibration was abandoned because additional simulations did not yield significant improvements in the calculated model performance indicators (R2 and E coefficients). For IFC, the application of SUFI-2 was very limited because it was possible to achieve acceptable results from SWAT with manual calibration techniques.

In the calibration process, surface runoff and base flow were simulated together. During the modelling, the amount of surface runoff was adjusted with curve number (CN2 in .mgt), ponds, soil characteristics (Table 4.2), and parameters controlling snowmelt (Table 4.1). The base flow was adjusted using selected groundwater parameters, the plant uptake compensation factor (EPCO in .bsn), and the soil evaporation compensation factor (ESCO in .bsn) (Table 4.1).

Table 4.2. Initial and final range of values for selected SWAT parameters from the SUFI -2 auto-calibration for Whelp Creek Sub-watershed (WHC) and Indianfarm Creek Watershed (IFC).

Selected parameters		Range of values					
		Initial		IFC final		WHC final	
Name in SWAT [z]	Description	Min.	Max.	Min.	Max.	Min.	Max.
v__CH_K2.rte	Effective hydraulic conductivity – main channel alluvium (mm hr^{-1})	0	150	0.05	5.50	0.50	3.50
v__SOL_ALB(1-5).sol	Moist soil albedo	0.01	0.25	0.05	0.15	0.02	0.13
r__SLSUBBSN.hru	Average slope length (m)	-0.1	0.1	na[y]	na	-0.06	0.15
r__PND_FR.pnd	Fraction of sub-basin area that drains into ponds	-0.1	0.1	na	na	-0.18	0.12
r__PND_PSA.pnd	Surface area of ponds when filled to principal spillway (ha)	-0.1	0.1	na	na	-0.06	0.13
r__PND_PVOL.pnd	Volume of water stored in ponds when filled to the principal spillway (10^4 m^3 water)	-0.1	0.1	na	na	-0.1	0.08
r__PND_ESA.pnd	Surface area of ponds when filled to emergency spillway (ha)	-0.1	0.1	na	na	-0.06	0.13
r__PND_EVOL.pnd	Volume of water stored in ponds when filled to the emergency spillway (10^4 m^3 water)	-0.1	0.1	na	na	-0.1	0.08
r__PND_K.pnd	Hydraulic conductivity through bottom of ponds (mm hr^{-1})	-0.1	0.1	-0.1	0.1	-0.12	0.14
r__WET_FR.pnd	Fraction of sub-basin area that drains into wetlands	-0.1	0.1	na	na	-0.19	0.06
r__WET_NSA.pnd	Surface area of wetlands at normal water level (ha)	-0.1	0.1	na	na	-0.09	0.12
r__WET_NVOL.pnd	Volume of water stored in wetlands when filled to normal water level (10^4 m^3 water)	-0.1	0.1	na	na	-0.11	0.07
r__WET_MXSA.pnd	Surface area of wetlands at maximum water level (ha)	-0.1	0.1	na	na	-0.09	0.08
r__WET_MXVOL.pnd	Volume of water stored in wetlands when filled to maximum water level (10^4 m^3 water)	-0.1	0.1	na	na	-0.11	0.07
r__WET_K.pnd	Hydraulic conductivity through bottom of wetland (mm hr^{-1})	-0.1	0.1	na	na	-0.09	0.14
r__CN2.mgt	Initial SCS runoff curve number for moisture condition II	-0.1	0.1	-0.1	0.1	-0.14	0.09
r__CH_N2.rte	Manning's "n" value for the main channel	-0.1	0.1	-0.1	0.1	-0.12	0.11
r__SOL_AWC(1-5).sol	Available water capacity of the soil layer (mm water/mm soil)	-0.1	0.1	-0.1	0.1	-0.08	0.14
r__SOL_K(1-5).sol	Saturated hydraulic conductivity (mm hr^{-1})	-0.1	0.1	na	na	-0.1	0.17
r__SOL_BD(1-5).sol	Moist bulk density (mg m^{-3} or g cm^{-3})	-0.1	0.1	na	na	-0.14	0.15

[z] Abbreviations for SWAT input file extensions: .hru = hydrologic response unit, .pnd = pond, .mgt = management, .rte = channel route, and .sol = soil.
[y] na = not applicable.

4.3.2 Setting Values for APEX Parameters

Parameters considered sensitive for the water balance, TSS losses, and nutrient losses were selected for calibration (Table 4.3). Before each simulation, one or more of the parameters was adjusted manually, and then after running the model, the predicted average monthly flow and total monthly losses were compared with the measured values.

The majority of the parameters selected for APEX calibrations were included in the PARM0604.dat and the APEXCONT.dat files. Table 4.3 shows the parameters that were calibrated, their acceptable range of values, and the values for IFC, WHC, and LLB.

Table 4.3. Parameter values for APEX calibrations for the Indianfarm Creek (IFC) Watershed, Whelp Creek (WHC) Sub-watershed, and Lower Little Bow River Field (LLB).

	Acceptable values	Final values		
Parameter description	Min. – Max.	IFC	WHC	LLB
	Parameter # (PARM0604.dat file)			
15- Runoff curve number weighting factor	0.0 – 1.0	0.4	0.0	0.4
16- Curve number retention factor	1.0 – 1.5	1.0	1.0	1.0
17- Soil evaporation – plant cover factor	0.0 – 0.5	0.5	0.5	0.5
20- Runoff curve number initial abstraction	0.05 – 0.4	0.30	0.20	0.3
22- Runoff curve number for frozen soil	0.05 – 0.5	0.05	0.15	0.15
25- Rainfall intensity coefficient	0.0 – 2.0	0.5	1.0	0.5
40- Groundwater storage threshold	0.001 – 1.0	1.0	1.0	1.0
42- Curve number index coefficient	0.5 – 1.5	0.5	1.3	0.5
44- Upper limit of curve number retention	1.0 – 2.0	1.7	1.2	1.7
49- Maximum canopy rainfall interception	2.0 – 15	10.0	4.0	4.0
50- Rainfall interception coefficient	0.05 – 0.3	0.05	0.25	0.05
61- Soil water tension factor	0.0 – 1.0	0.1	0.4	0.1
80- Soil radiation threshold for Snowmelt	10 – 20	20.0	16.0	10.0
18- TSS routing exponent	1 – 1.5	1.5	1.05	1.5
19- TSS routing coefficient	0.01 – 0.05	0.01	0.01	0.01
45- TSS routing travel time coefficient	0.5 – 10	3.0	5.5	3.0
46- RUSLE C-factor residue coefficient	0.5 – 1.5	1.0	1.0	1.0
47- RUSLE C-factor crop height coefficient	0.5 – 1.5	0.5	1.0	0.5
4- Water storage N leaching	0 – 1	0.7	0.1	0.7
14- Nitrate leaching ratio for surface runoff	0.1 – 1	1.0	0.1	1.0
30- Soluble phosphorus runoff exponent	1 – 1.5	1.5	1.0	1.5
32- Organic N and P transport exponent	1 – 1.2	1.0	1.0	1.0
62- Manure erosion equation coefficient	0.1 – 0.5	0.1	0.1	0.1
68- Manure erosion exponent	0.1 – 1.0	0.1	0.1	0.1
69- Manure erosion coefficient	1.0 – 1.5	1.5	1.2	1.5
72- Volatilisation/nitrification coefficient	0.05 – 0.5	0.2	0.3	0.2
74- Nitrate leaching ratio for return flow	0.01 – 0.05	0.05	0.03	0.05
	Parameter (APEXCONT.dat file)			
Maximum groundwater storage	5 – 200	50.0	100.0	50.0
Groundwater residence time in days	0 – 365	10.0	20.0	10.0
Return flow	0.0 – 1.0	0.1	0.02	0.1
Potential evapotranspiration equation		B.-R.[z]	B.-R.	B.-R.
Soil loss equation		RUSLE2[y]	RUSLE2	RUSLE2

[z] B.-R.: Baier-Robertson equation (Baier and Robertson 1965).
[y] RUSLE2: modified Revised Universal Soil Loss Equation (Renard et al. 1997).

The selection of the parameters in Table 4.3 was based on the sensitivity of these parameters on the model output. Initially, the default values were adjusted to match the APEX predicted flow, sediment loss, and nutrient losses with the measured data. Once a parameter value was established, the value was held constant for all sub-basins in each watershed. The parameter values in Table 4.3 were the result of calibration efforts for the two watersheds and one field site, and represented the final values used in scenario simulations based on water monitoring data through 2010. In addition to the parameters in Tables 4.1, 4.2, and 4.3, other parameters were used in APEX and SWAT and were set to default values. No model parameters or routines were excluded from the assessments. We anticipated the parameter values that resulted from the model calibration efforts were more appropriate than the model defaults for watersheds in Alberta.

The APEX model allows evaluation of groundwater elevation fluctuation on surface runoff. The user has the option of entering the minimum (min.), maximum (max.), and initial (init.) water depths, or use model default values. For the WHC and LLB calibrations, the groundwater parameters were estimated using the existing field measurements from WHC and field observations from LLB. However, for the IFC calibrations, model default values (min. = 50 m, max. = 100 m, and init. = 75 m) were used. The default values were assumed to be appropriate because measurements showed that the water table was generally deep (well below the maximum depth of the soil profile) and groundwater likely had little effect on surface runoff.

4.4 Calibration Results and Discussion

Early calibration of SWAT and SWAPP models (Olson and Kalischuk 2009) for the IFC and WHC watersheds showed that SWAPP had significant advantages over SWAT in predicting flow, sediment losses, and nutrient losses. Based on this observation, only SWAPP calibrations were continued for IFC, WHC, and LLB.

While reviewing the calibration results, it is important to recognize the results were also affected by the estimated values of SWAT and APEX calibration parameters (Tables 4.1, 4.2, and 4.3). Since the majority of these parameters were derived for the outlet of each watershed, the SWAPP predictions were also more improved at the watershed outlet than at the outlet of individual sites within the watershed. Also, it is important to note that in addition to model prediction uncertainty, there was also uncertainty associated with measured flow and water quality data used in model calibration. An earlier study (Harmel and Smith 2007) showed that uncertainty inherent in measured data is usually acknowledged but very often overlooked by the modellers during the calibration and validation processes due to the lack of data input on measurement uncertainty.

4.4.1 Indianfarm Creek Watershed

The comparison between monthly simulated and observed values showed that predicted flow, TSS losses, and nutrient losses were better for the main stream water monitoring stations (Stations 1, 5, and 11) than for the stations at the BMP sites (Stations 2, 4, 8, 9, 15, 18, and 21; Table 4.4). For the environmental indicators (i.e., flow, TSS, and nutrients), the R2 values ranged from 0.65 to 0.97 for the main stream stations and from 0.00 to 0.98 for the stations at the BMP sites. Similarly,

Table 4.4. Summary R^2 and *E* values for flow, total suspended solids (TSS) losses, and nutrient losses from SWAPP calibration for Indianfarm Creek Watershed (March 2007 to December 2010), Whelp Creek Sub-watershed (January 2008 to December 2010), and Lower Little Bow River Field (January 2008 to December 2010). Bold values represent main stream or major tributary stations.

	Flow		TSS		Nitrate N		Phosphate P		Organic N		Organic P		Total N		Total P	
Station	R^2	*E*	R^2	*E*	R^2	*E*	R^2	*E*	R^2	*E*	R^2	*E*	R^2	*E*	R^2	*E*
Indianfarm Creek																
1	**0.74**	**0.74**	**0.73**	**0.70**	**0.97**	**0.87**	**0.74**	**0.72**	**0.88**	**0.87**	**0.91**	**0.56**	**0.93**	**0.90**	**0.86**	**0.63**
2	0.38	0.19	0.16	0.03	0.00	-0.05	0.00	-0.07	0.14	-0.09	0.14	-0.03	0.02	-0.07	0.02	-0.08
4	0.74	0.67	0.84	0.83	0.48	0.32	0.98	0.56	0.94	0.53	0.88	0.87	0.63	0.41	0.96	0.73
5	**0.73**	**0.65**	**0.89**	**0.88**	**0.65**	**0.40**	**0.90**	**0.84**	**0.91**	**0.84**	**0.88**	**0.72**	**0.85**	**0.67**	**0.92**	**0.81**
10	0.26	0.50	0.26	0.52	0.00	-0.03	0.00	-0.05	0.01	-0.04	0.00	-0.04	0.00	-0.04	0.00	-0.05
11	**0.71**	**0.62**	**0.83**	**0.82**	**0.68**	**0.43**	**0.91**	**0.87**	**0.84**	**0.34**	**0.95**	**0.87**	**0.78**	**0.31**	**0.97**	**0.95**
15	0.34	0.34	0.25	0.14	0.00	-0.05	0.00	-0.03	0.00	-0.11	0.00	-0.30	0.00	-0.05	0.00	-0.04
18	0.51	0.51	0.41	0.40	0.54	0.42	0.71	0.67	0.14	0.09	0.54	0.51	0.51	0.34	0.68	0.67
21	0.62	0.84	0.72	0.83	0.02	-0.14	0.65	0.67	0.44	0.28	0.61	0.66	0.36	0.38	0.65	0.67
Whelp Creek																
301	**0.92**	**0.91**	**0.94**	**0.93**	**0.57**	**0.17**	**0.99**	**0.99**	**0.79**	**0.26**	**0.79**	**0.60**	**0.85**	**0.48**	**0.99**	**0.98**
303	**0.94**	**0.93**	**0.98**	**0.98**	**0.59**	**0.57**	**0.96**	**0.83**	**0.83**	**0.25**	**0.96**	**0.47**	**0.88**	**0.39**	**0.96**	**0.80**
307	0.13	-1.00	0.00	-0.29	0.00	-0.05	0.00	-0.04	0.00	-0.06	0.00	-0.04	0.00	-0.05	0.00	-0.04
309	0.85	0.79	0.97	0.79	0.56	0.02	0.75	0.71	0.94	0.06	0.19	-0.03	0.96	0.05	0.72	0.65
311	0.73	0.66	0.00	-0.07	0.19	-0.06	0.88	0.75	0.00	-0.09	0.00	-0.09	0.21	-0.05	0.87	0.67
314	0.52	0.51	0.31	0.08	0.21	0.05	0.02	-0.02	0.10	0.06	0.27	0.19	0.14	0.08	0.03	-0.01
318	0.25	-4.51	0.00	-0.03	0.64	0.63	0.13	-10.3	0.00	-0.03	0.00	-0.03	0.67	0.39	0.13	-3.60
319	0.90	0.78	0.97	0.43	0.10	0.02	0.97	-2.10	0.01	-0.15	0.11	-0.17	0.39	0.04	0.95	-1.41
324	0.70	0.67	0.00	-0.04	0.00	-0.06	0.00	-0.05	0.00	-0.05	0.00	-0.04	0.00	-0.05	0.00	-0.05
Lower Little Bow River Field																
101	0.71	0.69	0.26	0.23	0.34	0.29	0.68	0.58	0.14	-0.37	0.01	-0.19	0.57	0.33	0.70	0.65

the E values ranged from 0.31 to 0.95 for the main stream stations; whereas, the E values ranged from -0.14 to 0.87 for the BMP site stations. The SWAPP model predicted the IFC outlet relatively well, as all R2 values were generally greater than 0.7 and all E values were generally greater than 0.7, with the exception of the OP loss (E = 0.56). The predictions of flow and TSS losses were acceptable for two out of six field-scale stations. However, the predictions of nutrient losses were less accurate at most stations and E values were mostly less than 0.5 or in many cases negative. The implication is that the model performs better when dealing with larger watersheds than very small micro-watersheds or fields. This is particularly true when flow rates are very low in the watershed of interest. Factors such as differences in data precision (soil types, weather, and other data for specific field sites may be different from the average sub-basin level data used in simulations) as well as undocumented events make it difficult for the model to perform as well on small farm fields as opposed to large watershed areas where these precise data differences may even out.

A satisfactory performance of SWAPP at the main stream IFC stations can be attributed to the larger flow volumes and more prolonged periods of flow than at the BMP sites. Prediction of flow, TSS losses, and nutrient losses by field and watershed scale models, such as APEX and SWAT, is more reliable for areas with higher flow regimes (Saleh et al. 2000). This is due to better functionality of models and higher reliability of measured data for comparison. For example, the main stream stations experienced flow during 4 mo in 2007, 6 mo in 2008 and 2009, and 8 mo in 2010. The maximum average monthly flow at the IFC outlet was 5.0 m s-1 in June 2010 (Figure 4.1). In addition, the main stream stations flowed during snowmelt and rainfall events in each of the 4 yr. During these longer periods of flow, the TSS and nutrient losses had a better chance of achieving equilibrium with flow rates, and this resulted in satisfactory model performance.

The calibration results also showed that during the 4-yr period (2007 to 2010), SWAPP overestimated the rate of flow by 3%, TSS loss by 62%, PO4-P loss by 24%, ON loss by 20%, and TN loss by 8% at the IFC outlet (Station 1) (Figure 4.1). During the same period, the model underestimated the losses of NO3-N by 8%, OP by 46%, and TP by 30%. It is interesting to note that over and under predictions of nutrient losses were not consistent with overestimation of flow and sediment loss. Generally, we would expect that model overestimation of flow and TTS losses would also result in an overestimation of nutrient losses. However, this assumption was not true for IFC. This may indicate a complex fate and transport processes of TSS and nutrients in the IFC Watershed that the model cannot predict based on the input data provided for model calibration.

On the contrary, field-scale stations had much lower flow rates than the main stream, and the field measurements were subject to a greater range of flow variability. For example, the maximum average monthly flow ranged from about 0.001 to 0.030 m s-1 at Stations 21 and 18 during the 4-yr study period, respectively. The SWAPP prediction of these low flow events very often was in the margin of error of the field-scale model simulations. During calibration runs, it was discovered that minor changes in precipitation amounts (i.e., < 5 mm) had large effects on field-scale flow predictions. The majority of the BMP water monitoring stations did not have precipitation measurements. Therefore, there is a possibility that local precipitation variation may have caused greater differences between measured and predicted flows at the field-scale stations compared to watershed-wide stations.

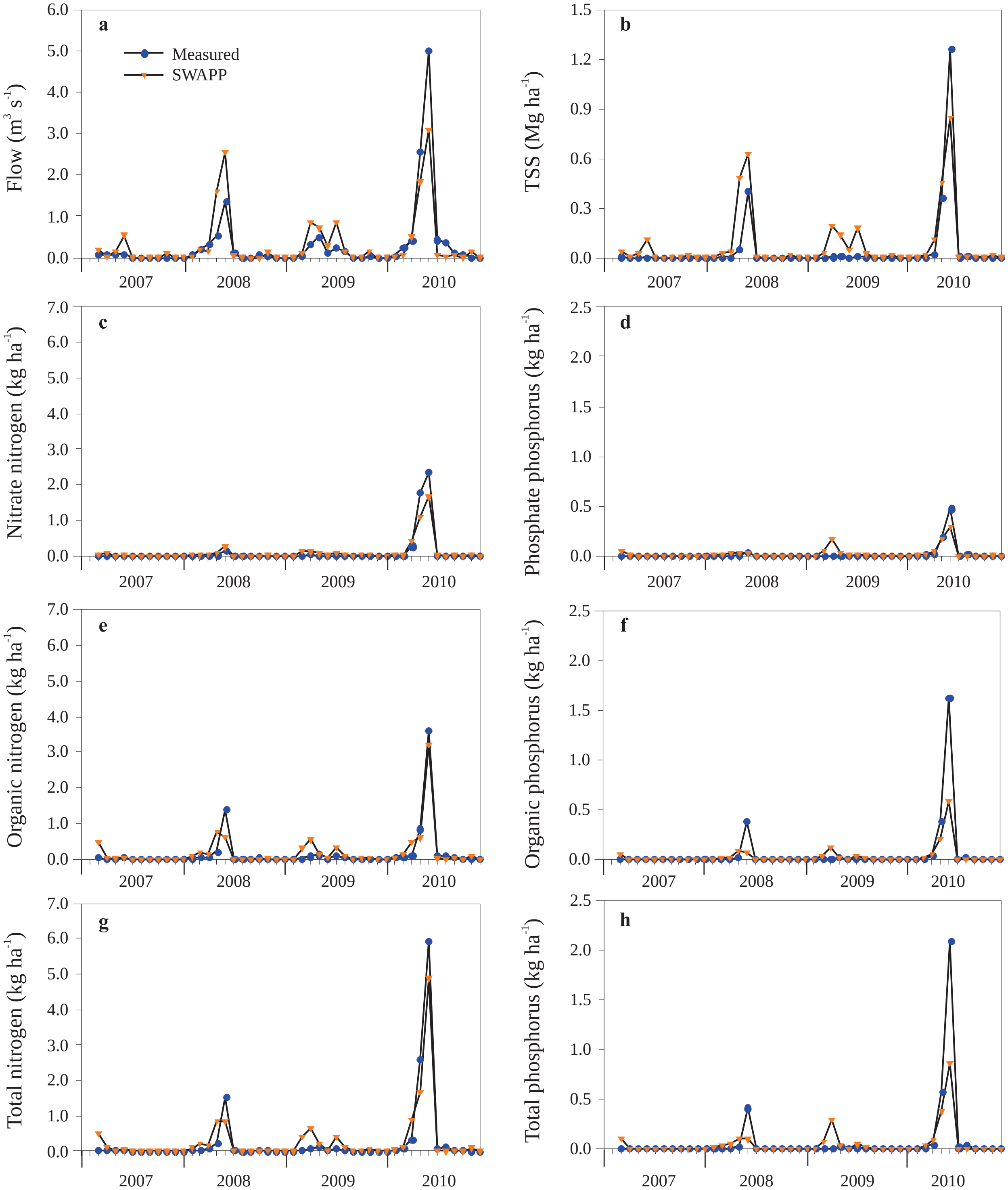


Figure 4.1. Measured and SWAPP-predicted average monthly values for (a) flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at the Indianfarm Creek Watershed outlet (Station 1) from 2007 to 2010.

The 4-yr (2007 to 2010) SWAPP prediction of nutrient losses at field-scale stations was also not consistent with the prediction of flow and TSS loss. Using Station 18 as an example, the model underestimated the rate of flow by 15%, NO3-N loss by 44%, ON loss by 66%, OP loss by 37%, TN loss by 54%, and TP loss by 8%. The model overestimated TSS loss by 3% and PO4-P loss by 1% (Figure 4.2). This was not a surprise if we consider the fact that the field-scale measurements of nutrient and sediment concentrations showed little or no correlation with the corresponding measured stream discharges (Table 2.6). This also may suggest that other factors may control the export of sediment and nutrients besides stream discharge.

4.4.2 Whelp Creek Sub-watershed

Similarly to IFC, the WHC calibration results showed that the calculated R^2 and E values at the mainstream stations (Stations 301 and 303) were higher than at the field-scale stations (Stations 307, 309, 311, 314, 318, 319, and 324; Table 4.4). At Stations 301 and 303, the R^2 and E values ranged from 0.57 to 0.99 and from 0.17 to 0.98, respectively. However, at the field-scale stations, there was a wide range of R^2 and E values, and the majority of the calibration results were not acceptable (i.e., R^2 and E values < 0.6). As mentioned above in Section 4.4.1, it is generally expected that computer simulation models would perform better on a larger scale than for very small field sites.

Satisfactory performance of SWAPP at the main stream stations can be attributed to the greater flow volumes (the maximum average monthly flow was 0.187 m s^{-1}; Figure 4.3) and longer duration of flows than at the field-scale stations. Similar to IFC, it appears that the TSS and nutrient losses had a better chance of achieving equilibrium with flow rates during larger and longer periods of flow. This was also reflected in the very good SWAPP predictions of large runoff events in 2010, which had a dominant effect on calculated R^2 and E values. Further analysis of the calibration results for the WHC outlet showed that during the 3-yr period, SWAPP underestimated the rate of flow by 16%, TSS loss by 29%, NO_3-N loss by 11%, PO_4-P loss by 4%, ON loss by 85%, TN loss by 74%, and TP loss by 2% (Figure 4.3). The model overestimated the total OP loss by 12%. It is interesting to note that PO_4-P was the dominate fraction of TP losses at the WHC outlet (Station 301) and that SWAPP was able to predict very well both fractions of TP (PO_4-P and OP) yielding R^2 and E values ranging from 0.79 to 0.99 and from 0.60 to 0.98, respectively (Table 4.4). However, a significant underestimation of ON can be related to inconsistency between field measurements of ON and OP fractions. For example, the measured ON fraction in TN was unusually high (Figure 4.3e, g) when compared to the measured OP fraction in TP (Figure 4.3f, h). In SWAPP, the export of ON and OP is directly related to TSS loss. Since the predicted TSS losses were low (Figure 4.3b), the predicted ON and OP fractions were also low (Figure 4.3e, f).

Less satisfactory prediction of SWAPP at the field-scale stations may be attributed to very low maximum average monthly flows and high flow variability among the monitoring stations. For example, in July 2010, during an extreme rainfall event, four out of seven stations did not record runoff. Of the three stations that did have flow, Station 309 had a maximum average monthly flow of 0.002 m s^{-1} (Figure 4.4). The other two stations had maximum flows less than 0.008 m s^{-1}. The fact that four stations did not generate runoff can be related to water storage. Field observations showed that water was stored in local depressions and there was no flow conductivity among sub-basins. The WHC Sub-watershed is characterized by a large number of wetlands, ponds,

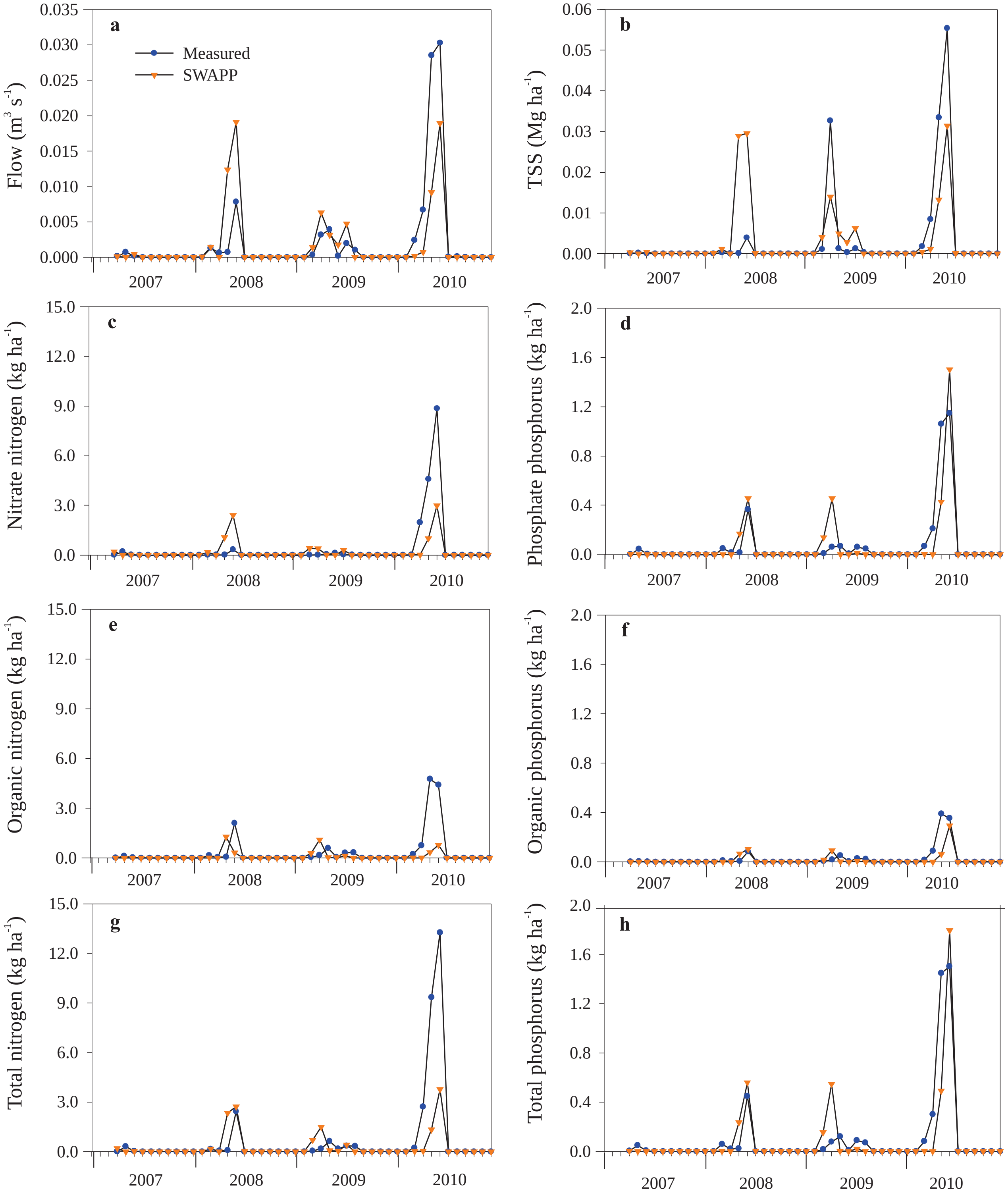


Figure 4.2. Measured and SWAPP-predicted average monthly values for (a) flow (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at Station 18 in the Indianfarm Creek Watershed from 2007 to 2010.

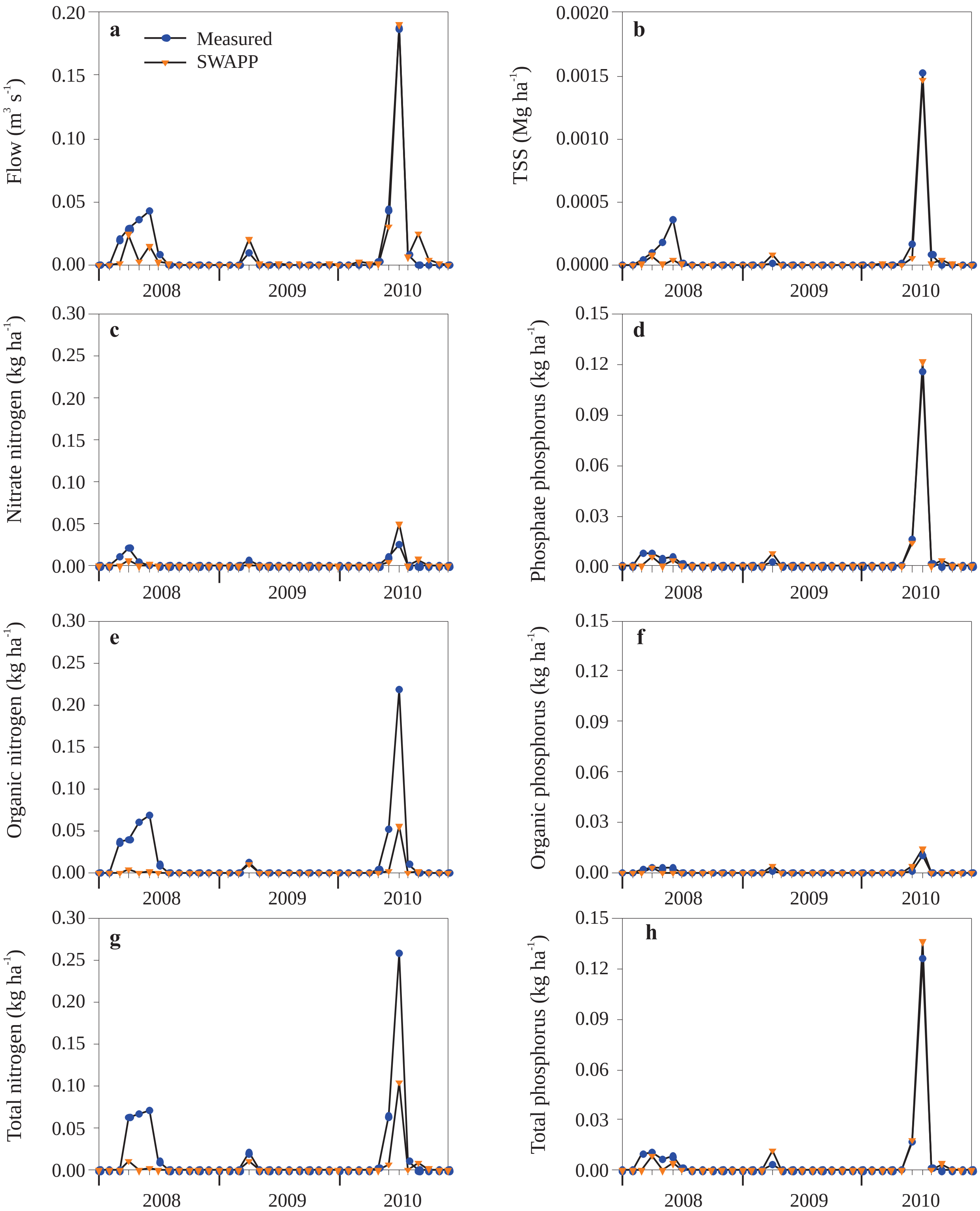


Figure 4.3. Measured and SWAPP-predicted average monthly values for (a) flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at the outlet (Station 301) of the Whelp Creek Sub-watershed in 2008, 2009, and 2010.

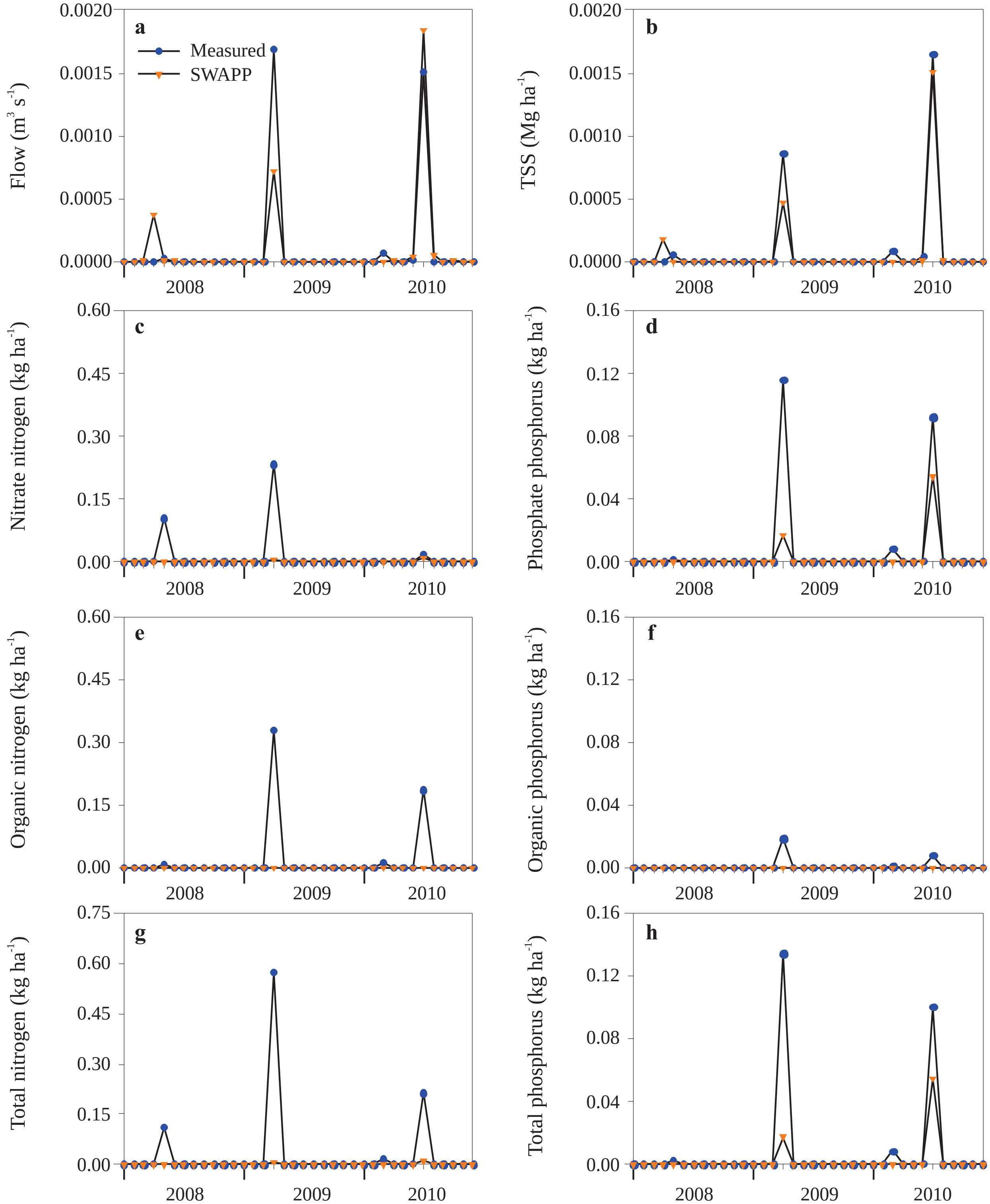


Figure 4.4 Measured and SWAPP-predicted average monthly values for (a) flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, (h) total phosphorus at Station 309 in the Whelp Creek Sub-watershed in 2008, 2009, and 2010.

impoundments, and depressions and these greatly affect flow rates at the field stations and eventually the main stream stations. It was difficult to accurately predict the storage capacity of these depressions due to limited accuracy of DEM input data (±0.75 m) used in the simulations. For minor flow events, the depressions will often not fill to capacity and flow is not connective. During these small events, SWAPP often predicted incorrectly that there was flow at the downstream station since the model prediction was in the margin of error of the field-scale model simulations. These water storage issues were likely compounded downstream through the WHC Sub-watershed.

It was expected that SWAPP would predict larger flow events with better accuracy because the storage depressions would fill and water would flow more freely through the WHC Sub-watershed. This was true at the WHC outlet (Station 301) and field-scale Stations 309, 311, 319, and 324 during the June 2010 runoff events. However, Stations 307, 314, and 318 did not meet these expectations because contrary to SWAPP predicted flow values, field observations did not report runoff events. This flow overestimation perhaps can be attributed to different amounts of precipitation at these stations. Since the available precipitation data used in the model was derived from only two stations, perhaps it was not sufficient to capture the spatial variability of rainfall intensity within the watershed.

As mentioned before, the lack of correlation between the measured and predicted values of flow, TSS loss, and nutrient losses during very low flow events was partly due to errors associated with the accuracies of measurement devices and model precision at this scale. In addition, the majority of the 2008 and 2009 field-scale runoff events were generated by snowmelt and the observed flow rates were impacted by the proximity of snow drifts relative to the flume locations. Field observation showed that the distribution of snow drifts varied from year to year within each sub-basin. Since the 2008 to 2010 snow precipitation was below the 30-yr average, the majority of snowmelt was intercepted by local depressions and very often snow drifts located near the flumes were the main source of the recorded flow.

Similar to IFC, it is important to recognize that the estimated values of SWAT and APEX calibration parameters (Tables 4.1, 4.2, and 4.3) and the lack of data input on measurement uncertainty had some effect on WHC calibration results.

4.4.3 Lower Little Bow River Field

Despite low average monthly flow rates, low TSS and nutrients losses, and rather small drainage area (Figure 4.5a), the calibration of flow, PO_4-P loss, and TP loss were relatively successful at the LLB site outlet (Station 101). The R^2 values ranged from 0.68 to 0.71 and the E values ranged from 0.58 to 0.69 (Table 4.4). However, the calibration of TSS, NO_3-N, ON, and OP did not yield good results and R^2 and E values were less than 0.5. This mixed performance of SWAPP can be attributed partly to discrepancy between observed flow discharge and corresponding nutrient and TSS losses. During the 2008 to 2010 period, for example, the observed average monthly flow peaks ranged from 0.0026 to 0.0031 m s^{-1} (Figure 4.5a). However, the observed corresponding average monthly export of TSS ranged from 0.0 to 0.11 Mg ha^{-1} (Figure 4.5b). Also, in 2009, the observed TSS losses were more than 10 times higher than in 2010, even though in 2009 the observed flow peak was about 25% less than in 2010. These observed TSS

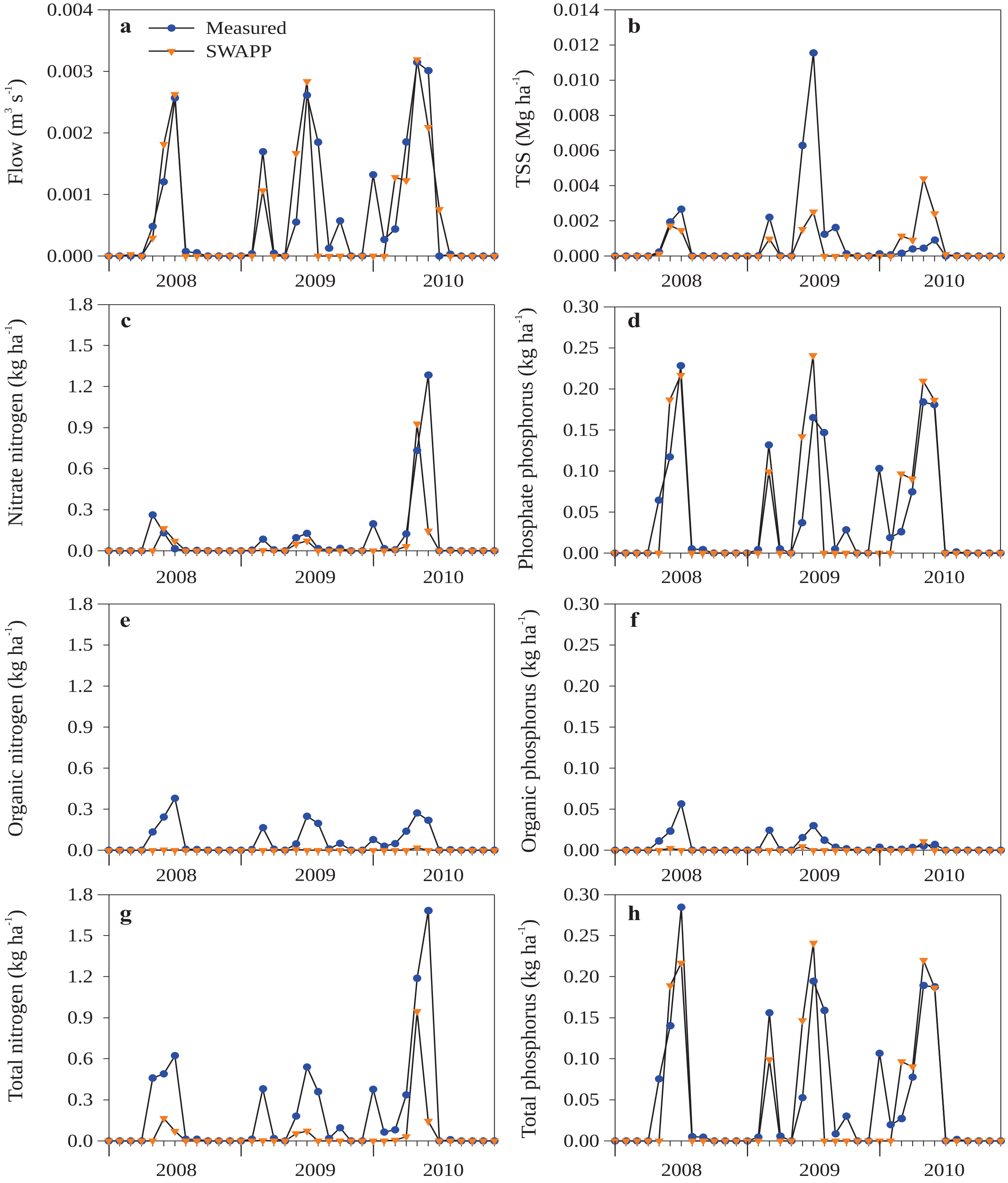


Figure 4.5. Measured and SWAPP-predicted values for (a) average monthly flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at Station 101 at the Lower Little Bow River Field site in 2008, 2009, and 2010.

losses were very difficult to model because the field observations did not provide additional explanation as to why this occurred. Perhaps this could be related to the surface disturbance and re-seeding of the grass in the drainage channel on July 3, 2009 (ARD 2014).

Further analysis of the calibration results at the LLB outlet showed that during the 3-yr period, SWAPP underestimated flow by 22%, TSS loss by 42%, NO_3-N loss by 43%, PO_4-P loss by 2%, ON loss by 99%, OP loss by 91%, TN loss by 76%, and TP loss by 21% (Figure 4.5). The measured and modelled data showed that LLB exported larger amounts of dissolved N and P fractions than organic fractions. In addition, better SWAPP prediction of flow rates resulted in better prediction of PO_4-P and TP losses (Figure 4.5a, c, d). However, a very poor prediction of TSS losses resulted in even poorer predictions of ON and OP losses (Figure 4.5b, e, f).

4.5 Summary of Calibration Results

The IFC and WHC calibration results showed that SWAPP produced fairly good predictions of the cumulative effects of BMP implementation on runoff, TSS, N, and P losses at the outlets of the main streams. Generally, the calculated R^2 and E values were larger than 0.60. A satisfactory model performance can be attributed to the relatively large flow rates and prolonged periods of flows under which the TSS, N, and P losses had a better chance of achieving equilibrium with flow rates.

On the contrary, SWAPP predictions were less accurate at the field-scale BMP sites where flow events were very low at IFC, WHC, and LLB. The calculated R^2 and E values were highly variable among BMP sites, and the majority of the R^2 and E values were < 0.60. Less accurate prediction can be related to (1) measured high variability of flow, TSS, and nutrients among monitoring sites; (2) very low flow conditions and limitations of model prediction at this scale, and; (3) lack of model input data on uncertainty inherent in measured data. Explanations for this disparity in model performance has also been provided in Sections 4.4.1 and 4.4.2.

Generally, it is during high runoff events when large amount of sediment and nutrients are exported from agricultural areas. The calibration results showed that SWAPP prediction of flow rate and TSS, N, and P losses was relatively successful during these events in the main streams. In spite of less satisfactory results at the field-scale sites and during low flows, SWAPP proved to be an effective tool for relative evaluation of cumulative effects of implemented BMPs in the agricultural watersheds.

5 BMP SCENARIO MODELLING

Beneficial management practice scenarios were simulated using the calibrated CEEOT model to predict the economic and environmental impacts of these practices in the IFC Watershed, WHC Sub-watershed, and LLB site. The environmental impacts were restricted to water flow and water quality indicators including sediment and nutrient losses at the outlets of sub-basins and the entire watersheds. Economic impacts were determined using typical farm enterprise cost and return indicators.

Two categories of BMP scenarios were simulated for the two watersheds and the LLB site: (1) a field study BMP scenario representing the distribution of monitored BMPs implemented in the watersheds during the field study and (2) non-monitored BMPs or policy scenarios. The field study BMPs were only simulated within the sub-basins where they were implemented and not simulated throughout the watersheds. The non-monitored BMP scenario represented three additional scenarios. Each scenario consisted of a combination of specific practices or policies that were not necessarily evenly applicable to all land-use parcels within each watershed.

In this study, while the same assumptions were used in the economic as well as the environmental simulations, the economic simulations were performed in separate FEM runs rather than within the CEEOT interface. This is because the CEEOT interface had not yet been upgraded to process information transfer between the three models for the types of scenarios that were evaluated. Nonetheless, the results from all three models are mutually consistent and were used to determine estimates of cost-effectiveness for the scenarios.

5.1 Development of Scenarios for Modelling

In total, five scenarios were evaluated for the IFC and WHC watersheds and the LLB site (Table 5.1). Scenario 1 was the baseline scenario, which represented the status quo without BMPs. Scenario 2 included only the BMPs implemented during the field study at the participating farms. Scenarios 3, 4, and 5 were developed based on consultation with the team leads of the BMP Project. These three scenarios included a number of practices that were considered to be relevant for each watershed and addressed four main concerns: (a) manure management, (b) livestock management, (c) erosion control, and (d) irrigation efficiency and runoff. Scenarios 1 through 3 were similar among the watersheds in terms of the broad definitions of the scenarios; whereas, Scenarios 4 and 5 differed among the watersheds to reflect different targeted concerns specific to each watershed.

5.1.1 Scenario 1: Baseline

For all three study areas, the baseline (status quo) scenario included the distribution of the existing farm management practices prior to the field implementation of the BMPs. The majority of the baseline scenario input data were very similar to the input data developed for model calibration since both datasets were prepared using the same farm survey reports (Sections 2.1.2 and 3.3). The main differences between these two datasets were in the inputs of land management and climate data.

Table 5.1. Scenarios simulated in the CEEOT model for the Indianfarm Creek W atershed (IFC), Whelp Creek Sub-watershed (WHC), and Lower Little Bow River Field (LLB). [z]

			Manure BMPs						Cow calf and riparian BMPs						
	Scenario	Field Study BMPs	Manure incorporation within 48 h	Manure AOPA setbacks	No application on snow	Soil nitrate nitrogen limits	Soil phosphorus limits	No manure applied in fall	Cattle restriction from creeks	Rotational grazing	15-m buffer strips	15-m grassed waterways	Wetland restoration	Reduced tillage in fall	Irrigation efficiency
IFC	2 (study)	X													
	3 (AOPA)		X	X	X	X									
	4 (cow-calf)		X	X	X	X			X	X	X	X			
	5 (P-limit)		X	X	X		X	X	X	X	X	X			
WHC	2 (study)	X													
	3 (AOPA)		X	X	X	X									
	4 (P-limit)		X	X	X		X	X							
	5 (riparian)		X	X	X		X	X			X	X	X	X	
LLB	2 (study)	X													
	3 (AOPA)		X	X	X	X									
	4 (P-limit)		X	X	X		X					X			
	5 (irrigation)		X	X	X		X					X			X

[z] Descriptions of the land-use management practices are provided in Sections 5.1.1 through 5.1.5 and in Appendix 1.

The farm survey indicated that most producers complied with Alberta Agricultural Operation Practices Act (AOPA) regulations but there were instances where this may not have been the case. For example, in many cases, setbacks for manure application were not provided during the survey, so it was assumed they were not implemented. Also, AOPA specifies that manure should not be applied on frozen ground without a permit of approval. The survey showed that one field received manure during March in IFC, prior to the expected spring rains. It was assumed this was done under a permit. The permit approval process ensures winter spreading occurs in a low risk area. Approval to apply in winter may be environmentally better compared to the alternative in a specific case, such a manure storage failure issue, for example. Based on the farm survey, for the few fields (n=5) that received manure in IFC, it was generally not incorporated within 48 h. Those fields may have been in forage or direct seeded where the regulations do not require incorporation, and most of the farmers in IFC have suggested incorporation is impractical due to wind erosion concerns. All the surveyed practises were reflected in the baseline scenario exactly as specified in the farm survey data for the specific farms, i.e., manure application in winter months in one case, surface application of manure without incorporation in IFC, and absence of manure application setbacks along common bodies of water.

For the BMP and other alternative scenario simulations, specific aspects of these management practices were altered as dictated by the requirements of the each scenario. Furthermore, in contrast to the calibration process, the survey management data were stretched over the 30-yr (IFC and WHC) and 35-yr (LLB) simulation periods for the purpose of simulating the baseline and alternative scenarios, and the corresponding climate data input files were also prepared for the entire simulation period.

A number of complications were encountered when defining the baseline (status quo) for land parcels where BMPs were implemented. Since most of the BMPs were implemented in stages with implementation times that differed from one site to another (Figure 1.2) it was sometimes difficult to determine when BMP implementation began and baseline (pre-BMP) management ended for a specific subarea. In such cases where a clear demarcation in time between pre-BMP and post-BMP management was not apparent, an approximate date was established and used to represent the end of pre-BMP management. For all BMP fields, only the pre-BMP management period was used to establish the baseline scenario.

5.1.2 Scenario 2: Field Study

A number of BMPs were implemented in the study watersheds to provide field measurement data for the evaluation of those practices (Table 5.2). Scenario 2 represented the post-BMP phase of the field study. Therefore, in this scenario most of the land base within the IFC and WHC watersheds had the same management practices as in Scenario 1 except for the few sites where the field study BMPs were implemented. Details of the field study BMPs are in ARD (2014). A brief description of the field study BMPs and their inclusion in the models is provided in the following sub-sections.

Table 5.2. Field study BMPs in the Indianfarm Creek Watershed, Whelp Creek Sub-watershed, and Lower Little Bow River Field.

Indianfarm Creek Watershed	Impoundment site (IMP)
	North Manure Field site (NMF)
	Pasture (PST) site
	Wintering site (WIN)
	South Manure Field site (SMF)
	Dairy Manure Field site (DMF)
Whelp Creek Sub-watershed	West Field site (WFD)
	North Field site (NFD)
	East Field site (EFD)
	South Field site (SFD)
	North Pasture site (NPS)
	South Pasture site (SPS)
Lower Little Bow River Field	Lower Little Bow River Field (LLB)

5.1.2.1 IFC Watershed

Impoundment site (IMP). The IMP site included a body of water created by an earth dam on a tributary of IFC and a surrounding pasture of about 35 ha. The BMP was cattle exclusion (about 5 ha) from the impoundment, using fencing and off-stream watering. In total, three subareas were defined for the cattle exclusion in order to accurately capture the routing sequence for the BMP. For this site in Sub-basin 2 (Figure 2.3), conventional practices (primarily grazing) were first simulated for all subareas during the baseline scenario. Next, the BMP was simulated by substituting a 'no grazing' management file for the management files that were used on areas immediately surrounding the impoundment. This model approach represented the installation of fencing to exclude cattle from the impoundment and the provision of off-stream watering.

North Manure Field site (NMF). The NMF site consisted of about 390 ha of annually cropped field with grassed drainage channels in the field. The BMP approach involved manure setbacks and exclusion of the fall grazing cattle along approximately 600-m grassed channels by fencing in fall 2010 and using livestock management tools. During the field study, manure was not applied on the field but this was modelled as a manure setback rather than exclusion. Upon detailed review of the spatial distribution of the fields, the NMF site was divided into six subareas (about 65 ha each), reflecting soil and crop variations as well as the differences in management between the baseline scenario and the BMP implementation on this site. Conventional practices (including status quo grazing practices and livestock access to streams) were simulated on all subareas in the baseline scenario. For the simulation of this BMP, a “no-grazing” management file that entailed minimal application of inorganic fertilizer in the whole field (including drainage channel) and no manure application within 30 m of the drainage channel were simulated to mimic a manure application setback in Sub-basin 6 (Figure 2.3). For modelling purposes only, inorganic fertilizer rates used in the setback area were lower than the agronomic rates, but sufficient to maintain good crop cover.

Pasture site (PST). The PST site was a 121-ha area with several small pastures that were used for cattle grazing. During the grazing season, cattle had continuous access to IFC, which flowed through the site. The PST site also included an old corral structure that drained into a tributary of IFC. A total of 14 subareas (about 80 ha) were defined for the PST site by dividing existing subareas into smaller fields in order to facilitate simulation of BMPs for this site. The BMP involved removal of the corral structure next to IFC mainstem in Sub-basin 1, and the implementation of rangeland management tools to promote rotational grazing. Exclusion was targeted on the riparian pasture area during the most sensitive time of the grazing season, in terms of risk to the riparian area (May and June). In addition, a new windbreak and off-stream watering system was installed in Sub-basin 1. The baseline entailed an alfalfa-oat rotation, whereas, for the BMP scenario a continuous rotational pasture land use was implemented, to reflect the BMP implementation plan. Pre-BMP management practices were simulated as baseline grazing conditions during the baseline scenario simulation. During BMP scenario simulation in Sub-basin 7 (Figure 2.3), the majority of the subareas were simulated with alternative grazing schedules to reflect improved management practices. In particular, cattle were moved among several pastures to minimize overgrazing and improve vegetative cover. On a few of the subareas at this site, a “no-grazing” management practice was simulated to reflect instances when cattle were excluded from that area or were moved to other fields for grazing.

Wintering site (WIN). The WIN site was a farmstead on IFC that had a cattle winter feeding and bedding area, which drained directly into the creek. Cattle had direct access to the creek during the grazing season. The BMP in Sub-basin 13 entailed relocation of the wintering site to a new site further away from the creek (Sub-basin 9; Figure 2.3). The BMP also included fencing and off-steam watering to limit cattle access to the creek and riparian area during the more sensitive part of the grazing season. Similar to the sites previously described, the pre-BMP management practices were simulated as baseline grazing conditions during the baseline scenario simulation. Also, special management files were created for various subareas to simulate post-BMP implementation practices. To adequately simulate this scenario, the entire wintering site was divided into 12 subareas (about 68 ha). The subarea divisions were necessary to simulate the above mentioned BMPs.

South Manure Field site (SMF). This was a 57-ha field where manure was surface applied in small piles in the fall, and then levelled in the spring. Due to logistic and weather factors, a BMP plan was not implemented at this site during the field study. However, a manure setback (30 m) on either side of 700-m long drainage channel was simulated in Sub-basin 19 (Figure 2.3). For the simulation, the setback (about 6 ha) received very little inorganic fertilizer and no manure applications.

Dairy Manure Field site (DMF). The main component of this BMP site was discontinuation of manure application during winter months in selected areas due to elevated STP in the soil. Three unique subareas (about 15 ha) were delineated based on the intersections of fields and HRUs for BMP simulation in Sub-basin 4 (Figure 2.3). The BMP scenario was simulated by substituting 'no manure application' management files for the management files that were used in baseline scenario simulation.

5.1.2.2 WHC Sub-watershed

West Field site (WFD). The WFD site (65 ha) was an annually cropped field. The BMPs at this site included a nutrient management plan for poultry manure application and 30-m setbacks from the drainage channel in the field. Five unique subareas (about 34 ha) were created at the WFD site after overlaying the field boundaries with the HRU distributions in Sub-basin 4 (Figure 2.4). The pre-BMP manure management practices were simulated for the baseline scenario. In the BMP scenario, a manure setback was simulated for both sides of the drainage channel. As with the IFC setbacks on the BMP monitoring sites, the manure setbacks in the WHC BMP monitoring sites received no manure applications and a very low rate of inorganic fertilizer. The fertilizer application was lower than the agronomic rate, but sufficient to maintain good crop cover. In the remaining area of Sub-basin 4, the model simulated poultry manure applied based on 3 to 4 yr of crop P removal.

North Field site (NFD). The NFD BMPs consisted of 30-m wide manure setbacks from the drainage channel, nutrient management plans for manure application, a change from surface to injected liquid manure application, some erosion control, and relocation of a solid manure storage area. In the BMP scenario simulation for this site (about 7 ha), the setbacks were implemented on three subareas located west of the main stream in Sub-basin 1 (Figure 2.4) and on one subarea located east of the main channel in Sub-basin 3. In addition, the manure storage was relocated from one subarea in Sub-basin 1 to a different subarea in Sub-basin 2. Similar to WFD, the setback subareas received a very low rate of inorganic fertilize and no manure.

East Field site (EFD). The intended BMPs could not be implemented at this site because of a change from annual to forage crop cover early in the study. Instead, liquid manure was surface applied to the forage crop using a nutrient management plan and setbacks were implemented on both sides of the drainage channel (about 6 ha). The field changes provided a novel opportunity to examine the environmental impacts of a nutrient management approach where, theoretically, a farmer had excess manure and a limited land base. The above mentioned BMPs were implemented and simulated on three subareas in Sub-basin 5 (Figure 2.4).

South Field site (SFD). This site was an annually cropped field covering the majority (60 ha) of a quarter section. Two drainage channels originated from the west side of the field, merged within the field, and exited the field near the northeast corner. The BMPs included surface application of liquid dairy manure based on a nutrient management plan and using 30-m manure setbacks along the drainage channel near the exit point. The SFD site had four unique subareas (about 45 ha) where the BMPs were implemented. Manure setbacks were simulated directly south of water monitoring Station 314 in Sub-basin 10 (Figure 2.4). As with the other setbacks, these manure setbacks also entailed no manure applications and minimal inorganic fertilizer application to maintain vegetative cover. In the remaining area of Sub-basin 10, liquid dairy manure was applied based on crop N requirements.

North Pasture site (NPS). This site was a 4-ha pasture bisected by Whelp Creek. The BMP was the use of an additional 5 ha of pasture area to effectively reduce the stocking density. In 2009, the grazing area was increased to 9 ha. The NPS site had six unique subareas in Sub-basin 17 (Figure 2.4). In contrast to the baseline, grazing was simulated for all subareas except for a small area (about 10 by 15 m) near water monitoring Station 301, where WHC entered the pasture. This 10- by 15-m area was a bioengineering site, which was fenced and excluded from grazing to promote willow grow. The model simulated no grazing in this area.

South Pasture site (SPS). This site was a heavily grazed, 36-ha pasture. The BMP included dividing the pasture into three paddocks using electric fencing and a watering system, and rotating the cattle among the paddocks during the grazing season. The SPS site had four unique subareas in Sub-basin 13 (Figure 2.4). The pre-BMP management practices were simulated as open access grazing with no watering system or fencing during the baseline scenario simulation. Rotational grazing was simulated on all four subareas under the BMP scenario. The specific grazing schedule used in the actual field implementation was also simulated in the model runs.

5.1.2.3 LLB Field Site

The LLB site was a 130-ha annually cropped field with two centre pivot irrigation systems. The soil in the field contained very high STP concentration (>200 mg kg^{-1}) in the top 15 cm of soil due to beef cattle manure application. The BMPs included discontinuation of manure application (i.e., no P additions) on the entire field, establishment of a grass channel, and soil nutrient management to determine if inorganic fertilizer N was required. Manure applications were allowed only when soil P levels became less than 60 kg ha^{-1}. Also, irrigation was discontinued in a small area (a few hectares) of excessive wetness near the drainage channel outlet. Irrigation application was monitored and maintained at approximately 80% of the total available water.

In the baseline scenario, manure applications were simulated as reflected in the survey data showing that manure was applied once every 3 yr on the subareas. Furthermore, irrigation scheduling was maintained as specified in data obtained on current practices of the farm. In the BMP scenario, manure application was allowed only when STP concentration became less than 60 mg kg^{-1}, which is considered the agronomic threshold above which added P is general not required to achieve optimum crop growth (Howard 2006). An iterative procedure was used to determine when STP concentration became less than 60 mg kg^{-1} and manure application could be resumed.

5.1.3 Scenario 3: AOPA

The AOPA in Alberta includes regulation for manure application to fields (Province of Alberta 2010). The baseline scenario included AOPA standards, as the regulations were enforced at the time. However, as previously mentioned, there were instances in the Baseline Scenario where practices were not environmentally optimal such as surface application of manure without 48 h incorporation, manure application in winter months, and the absence of manure application setbacks. Scenario 3 permitted an opportunity to evaluate AOPA regulations considering the most environmentally ideal practices, regardless of practicality or ability of the farmer to implement them. Four parts of the AOPA manure management regulations were considered for Scenario 3. Of the four parts, only the manure application setbacks distinguish the Baseline Scenario and Scenario 3, as both model scenarios were almost compliant with application based on NO_3-N, incorporation in 48 h, and no winter application. Scenario 3 for the LLB site also included the irrigation application rates specified for Scenario 2.

- **Manure application based on nitrate nitrogen concentration in the top 60 cm of soil.** The survey data suggested farmers in the watersheds were compliant with this regulation. Therefore, this practise was included in the Baseline Scenario for the 30 or 35 yr of simulation. The regulations specify that manure can only be applied on fields if the soil NO_3-N concentration is less than a given threshold based on soil testing (Table 5.3). The NO_3-N limits vary according to soil type, soil texture, and depth to water table. To simulate this requirement, an iterative procedure was used to determine soil NO_3-N concentrations at the end of each year of simulation. Manure applications in the following year were then predicted upon whether the soil NO_3-N concentration exceeded the predetermined threshold. The APEX operations files were modified accordingly and the entire simulation was executed for all subareas.

Table 5.3. Soil nitrate nitrogen (NO_3-N) limits in the top 60 cm of soil in AOPA for fields receiving manure (Province of Alberta 2010).

	Soil texture		
	Coarse textured soils (>45% sand)		Medium and fine textured soils
	<4 m to water table	>4 m to water table	
Soil type	----------------------- (kg ha^{-1} NO_3-N) -----------------------		
Brown	80	110	140
Dark Brown	110	140	170
Black	140	170	225
Gray Luvisol[z]	110	140	170
Irrigated	180	225	270

[z] The old term Grey Wooded is used in the Act (Province of Alberta 2010).

- **No manure application on frozen or snow-covered land.** The Baseline Scenario included one instance of manure application in the winter in IFC, as specified in the survey responses. A couple of the field BMPs under Scenario 2 modelled no manure application in the winter, and in those cases, the specific management indicated in ARD (2014) was used in the model. For Scenarios 3, 4, and 5 where no manure application was permitted in the winter, the model simulated application in the spring or summer of the same year.

- **Manure incorporation within 48 hours of application.** The AOPA specifies that manure applied on cultivated fields must be incorporated within 48 h (two days) after application. The model permits the user to define the time of manure application, so for Scenarios 3, 4, and 5, as well as for subareas that used manure incorporation in Scenario 2, a maximum of 48 h was used as opposed to the Baseline Scenario, where in a few instances manure was not incorporated. To simulate manure incorporation, manure applications were modified to include a tillage depth in the APEX operation listing file. This implied that manure was incorporated immediately after or during application. In FEM, an additional tillage operation was used within 48 h if no tillage operation already followed the manure application.

- **Setbacks for manure application.** Setbacks from common bodies of water are required for fields that receive manure. In AOPA, manure must not be applied within 10 m of a common body of water when using sub-surface injection. This would apply mainly liquid manures. Manure that is surface applied and incorporated within 48 h cannot be applied within 30 m of a common body of water. For surface applied manure that cannot be incorporated, such as winter spreading, or spreading on forages or direct seeded land, the width of the setback area depends on the slope of the field (Table 5.4). To model this, the size of the setback area was based on the applicable width, and the area of the main field was reduced by the size of the setback. On the setback areas, manure applications were eliminated, and although not required by AOPA, the simulation assumed no supplemental fertilizer applications were used. Setbacks were required under Scenarios 3, 4, and 5. The modelling of setbacks applied to many fields, as many common bodies of ephemeral water existed. It is important to note for Scenario 2, the specific management indicated in ARD (2014) was used in lieu of general AOPA specifications. In particular, Scenario 2 included the addition of commercial fertilizer application on a number of the setbacks.

Table 5.4. Manure application setback widths under AOPA regulations for unincorporated, surface applied manure (Province of Alberta 2010).	
Mean slope within 90 m of a common body of water	Setback width (m)
≤ 4%	30
> 4 to < 6%	60
6 to <12%	90
≥12%	no manure application

5.1.4 Scenario 4: IFC Cow-calf and WHC/LLB P-limits

Scenario 4 differed among the three study areas. For IFC, Scenario 4 (cow-calf) included Scenario 3 plus the following four cow-calf and riparian management practices:

- **Cattle restrictions.** Cattle access to streams, creeks, or other water bodies was restricted. This involved total exclusion for an extended period of time, and was applied to all subareas adjacent to streams, creeks, and other water bodies. This is in contrast to cattle restrictions that were required under the BMP scenario, where this restriction was applied to only a few subareas, such as the Impoundment site. Cattle exclusion was simulated by inserting a subarea on the downstream edge of the main field and eliminating all grazing operations that were scheduled to occur in the new subarea.

- **Rotational grazing.** Rotational grazing was applied to cattle pastures when required for the specific scenario. Rotational grazing is the practice of moving cattle from pasture to pasture in a scheduled fashion in order to improve pasture conditions, particularly for riparian pastures during the more sensitive period of the grazing season (i.e., in the spring) when these pastures are at higher risk to degradation by cattle access. The rotations were designed so that cattle were excluded from riparian pastures, and the associated creeks or streams, during the more sensitive periods.

- **Vegetative buffer strips.** Buffer strips were placed on a portion of the field adjoining dugouts, wetlands, and other water bodies other than streams. The purpose of a buffer strip is primarily to filter sediments and reduce runoff flow velocity and edge-of-field erosion. In the simulations, buffer strip width was set at 15 m and consisted of perennial pasture vegetation.

- **Grassed waterways.** Drainage channels within cultivated fields were converted to permanent grass cover simulated at a 15-m width.

Scenario 4 (P-limit) for WHC and LLB included Scenario 3 as well as manure application based on P uptake rate of receiving crops and no fall application. Manure application in the spring and summer may reduce nutrient losses compared to fall application of manure, which is at a higher risk of nutrient loss during spring snowmelt events. Scenario 4 for LLB also included the irrigation application rates specified for Scenario 2.

5.1.5 Scenario 5: IFC P-limit, WHC Riparian, and LLB Irrigation

For the IFC Watershed, Scenario 5 (P-limit) included all of the features of Scenario 4 in addition to manure application based on P uptake rate of crops and no manure application in the fall or winter.

Scenario 5 (Riparian) for WHC augmented Scenario 4 with riparian management practices, restrictions on fall tillage as well as wetland restoration. To simulate the wetland restoration feature of this scenario, a portion of all subareas adjacent to wetlands, dugouts and other water bodies other than streams was simulated as a wetland. Specifically, wetland vegetation was grown on a 15-m strip of each applicable subarea and no farming operations were performed on that strip.

For LLB, Scenario 5 (irrigation) included Scenario 4 and automatic irrigation scheduling (based on an assumed 15% crop water stress factor depletion of plant available soil-water capacity used to trigger irrigation) and irrigation was prevented in critical runoff source areas.

5.2 Modelling Assumptions, Specifications, and Limitations

5.2.1 General Model Specifications

Once CEEOT calibration was completed, the initial values of model parameters and coefficients were established for each watershed for the BMP scenario simulations. Also, the majority of model input data used in model calibration was included in the input data of BMP scenarios with the exception of land/farm management and climate input data. The new management input data files were prepared for all the BMP scenarios for IFC, WHC, and LLB watersheds to represent the BMP management practices that were incorporated in each scenario. In addition, the climate input files used in model calibrations were modified. The new files used 30 yr (from 1971 to 2000 for IFC and WHC) and 35 yr (from 1971 to 2005 for LLB) of climate data available from the nearest weather stations instead of 8 or 10 yr used in model calibration.

One assumption implicit in all BMP scenarios is that any manure generated on-farm but not applied within that watershed was hauled out of the watershed and applied elsewhere. In particular, for the scenarios in which manure applications were based on the P uptake rate of crops (Scenario 5 in IFC; Scenarios 4 and 5 in WHC and LLB), or based on soil P (Scenario 2 in LLB) or N (Scenario 3 in all watersheds) levels, any manure not applied on the subareas included in the simulations was assumed to be hauled out of the watershed with an average hauling distance of 8 km. Thus, the environmental results for those scenarios would reflect a reduced amount of manure nutrient application in the watershed. However, the economic implications of hauling manure a greater distance, even outside of the study watersheds, was included in the evaluation.

5.2.2 Routing Sequence for Project Watersheds

Information on the hydrological routing sequence between sub-basins is pertinent to a correct understanding of the environmental impacts of simulated scenarios at the sub-basin level and at the outlet of each watershed. This is because the values of environmental indicators at the outlet of each sub-basin are greatly influenced by flow emanating from upstream sub-basins, and ultimately the environmental indicators at the outlet of each study watershed are influenced by the values of the respective indicators in all upstream sub-basins.

The sub-basin-level routing sequence for each watershed is presented in Figures 5.1 and 5.2. The outlet for IFC watershed was in Sub-basin 1 and the outlet of WHC watershed was in Sub-basin 20. The LLB site had only two sub-basins and its outlet was in Sub-basin 1 (Figure 2.5a).

5.2.3 Model Specifications that Differ among BMP Scenarios

This sub-section outlines the unique assumptions, specifications, and limitations that were used in the CEEOT simulations for each of the scenarios. Since the unique model specifications were defined according to the scenario features, the presentation here is organized by scenario feature rather than by watershed.

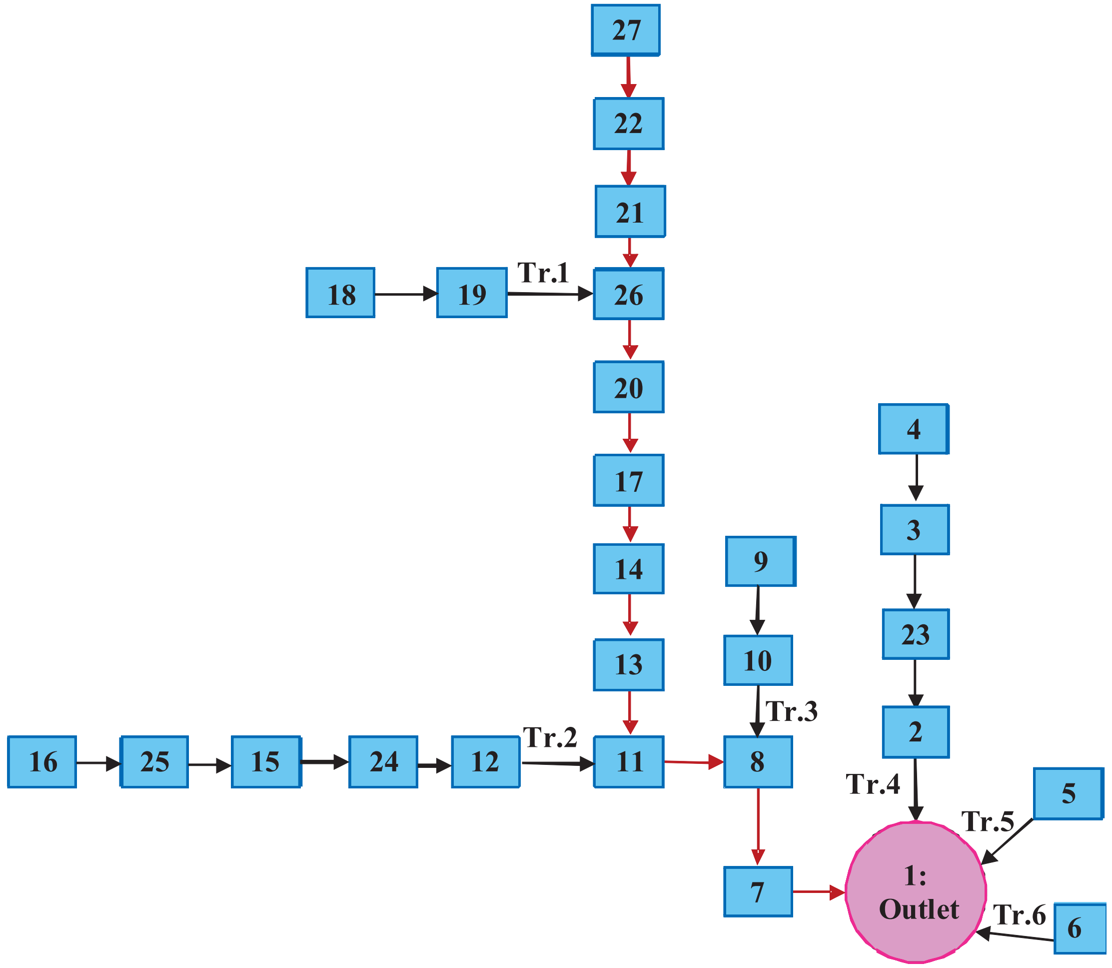


Figure 5.1. Sub-basin model routing sequence for the Indianfarm Creek Watershed. The creek tributaries (Tr) are marked with black arrows and the main creek is marked with red arrows.

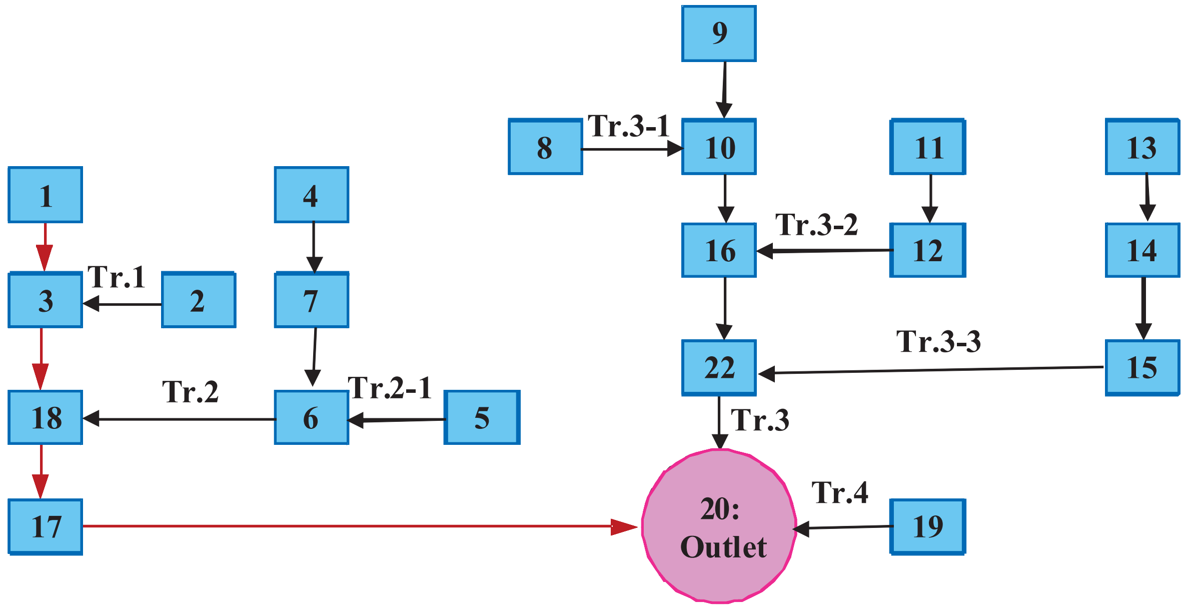


Figure 5.2. Sub-basin model routing sequence for the Whelp Creek Sub-watershed. The creek tributaries (Tr) are marked in black arrows and the main creek is marked with red arrows.

5.2.3.1 Manure Incorporation

To varying degrees, this management practice is a component of all scenarios, including the baseline. The models define this practice as liquid manure injection or solid manure incorporation, whereby solid manure that is surface applied is tilled into the soil within 48 h of application. A number of producers were already incorporating manure within 48 h of application, and therefore would effectively have this BMP scenario practice on their fields in the baseline scenario. Thus, in the baseline scenario, manure was incorporated on a few fields. However, in scenarios that required manure incorporation, all fields receiving manure were simulated as having the manure incorporated within 48 h of application.

To simulate this management practice, two main options are present in CEEOT. The first option is to specify a nutrient application depth in the APEX model (in the operation file). The second option is to add an appropriate tillage operation in the operation file after and within 48 h of the manure application operation. For this study, the first option was used; however, the additional utilities created for these scenario simulations allowed us to use the second option as well, just by specifying that option when running simulations. A 7.62-cm (3 inch) depth was assumed for the manure incorporation scenario.

5.2.3.2 Manure Setbacks

This scenario management practice is in Scenarios 3, 4, and 5. Manure setbacks were simulated in the environmental and economic models as separate areas within the crop (parent) fields. Based on model specifications assumed for the scenarios, these setbacks did not receive manure or inorganic fertilizer, but were otherwise treated the same as the parent crop field. Thus, the same crop was grown in the setback as the main field and the same cultural practices, weather, and soil attributes were used.

In the environmental simulations, it was assumed that flow was routed from the main field through the setback before leaving that subarea. To calculate the area for the setback, a square configuration was assumed for the parent main field (length by width). This assumption was made because it was impossible to determine the configuration of every field individually and a square configuration would serve as a good average for most cases. The area of the setback was calculated as the setback width (as specified in AOPA) times the length of the main field (which equals the width of the field since a square configuration was assumed).

In the economic model simulations, a separate field was assigned to the setback with a size equal to the setback width times the length of the main field, as described above. A yield penalty was used for the setback area since no supplemental nutrient application was assumed.

The reduction in nutrient applications in the setback area will generally lead to yield reductions. Yield reduction would result in less biomass cover on the setback area, and this may result in a greater potential for sediment runoff. Thus, without supplemental nutrient applications, the setback areas, as simulated, may result in increased sediment and particulate nutrient losses from the entire field. However, some fields, with a long history of manure application and an excess of residual nutrients in the soil, may not experience yield reductions without added fertilizer for several years.

5.2.3.3 Soil Nitrate Nitrogen Limits on Manured Fields

For Scenarios 3, 4, and 5, soil NO_3-N limits were simulated by pausing the APEX simulation at the end of each year to determine whether or not the soil NO_3-N level exceeded the thresholds specified in AOPA (Table 5.3). If the soil NO_3-N level exceeded the threshold, manure applications scheduled for the next growing season were eliminated. The soil NO_3-N limits are not applicable to inorganic fertilizers, so fertilizer application was maintained for each year of simulation at the baseline rates.

5.2.3.4 No Manure Application on Frozen or Snow-covered Land

For scenarios 3, 4, and 5, all manure applications that were scheduled for dates with high probability of snow cover or frozen conditions were moved to a different time during the spring, summer, or fall of the same year when the possibility of snow or frozen conditions were negligible. Specifically, manure applications originally scheduled for late October through March were moved to the time of planting in spring, usually in May. This is in contrast to the baseline scenario where manure applications were maintained on those dates regardless of the possibility of snow cover or frozen conditions.

5.2.3.5 Soil-test Phosphorus Limits

Soil-based P-limit. For the LLB Scenario 2 (P-limit), manure application was restricted until STP levels in the top 15 cm of soil were reduced to 60 kg ha^{-1}. As in the NO_3-N soil limit simulations, the APEX model was iterated in progressive steps. First the simulation period was set to 1 yr. The model was then simulated for each subarea using the management practice information specified in the baseline scenario for that subarea. At the end of the simulation, the STP concentration was read from the APEX output files. The simulation was then repeated for 2 yr. For this second simulation, any manure applications scheduled for Year 2 were eliminated if the STP concentration reached or exceeded 60 mg kg^{-1}. This procedure was repeated for 3 yr, 4 yr, and so on until the model had been executed for the entire 35-yr time horizon. The revised management file for each subarea was then used for the BMP simulation.

Agronomic P-limit. For Scenario 5 in IFC and Scenario 4 in WHC and LLB, the manure application was based on agronomic P requirements, or the P crop removal. The implications of the soil-based versus agronomic P-limits will be manifested in the soil. In the case of the soil-based approach, there will be a drawdown in STP to at least 60 mg kg^{-1} concentration. In the case of the agronomic P-limit approach, STP will not change (i.e., should remain static) as the amount of P added should match the amount of P removed by the crop.

5.2.3.6 Reduced Tillage

Reduced tillage entailed elimination of all deep tillage operations that occur in the fall or winter months. This feature applied only to Scenario 5 for the WHC watershed simulations.

5.2.3.7 Wetlands

Wetlands restoration or wetlands development was simulated by creating a 15-m wide subarea along the edge of the field that borders the water body. A special APEX operation file was used for this wetland subarea that triggered the wetland simulation routine in APEX. The sub-basin file was appropriately modified so that flow from the upland area of a field routed through the wetland prior to leaving the field.

5.2.3.8 Cattle Restrictions

This scenario feature entailed elimination of cattle access to the streams or other water bodies. However, since this scenario feature was used in combination with other riparian structural controls including setbacks and buffer strips or wetlands, no additional model specifications were applied. Specifically, the setbacks, buffer strips, and wetlands introduced subareas between the field and the water body that did not include grazing. Consequently, there was no need to further introduce an additional restriction for this scenario feature.

5.2.3.9 Rotational Grazing

Rotational grazing was simulated in all scenarios other than Scenario 2 with the objective to improve pasture conditions. This scenario feature was implemented by improving the curve number of grazed pastures where this feature applied, in comparison to pastures where open access, unmanaged grazing occurred.

5.2.3.10 Grassed Waterways

As with the wetlands, a 15-m subarea was created within the upland field and simulated as a grassed area that mimicked a buffer strip or filter strip. A special APEX operation file was used to account for this feature, which also triggered the filter strip routine within APEX. All flow from the upland area of the field was routed through the waterway prior to leaving the field.

5.3 Simulation Procedures and Interpretation of Results

The results presented below are annual averages of the 30 yr (IFC and WHC) and 35 yr (LLB) simulation horizons. Specifically, the impacts presented were computed as follows. First, the average annual environmental losses at the outlet of each of the watersheds were calculated by taking the average of all 30 or 35 annual SWAT output values for each environmental indicator. Annual average losses were computed for all five scenarios: the baseline and the four alternative scenarios. The environmental impacts for each alternative scenario were determined as percentage changes of each indicator value relative to the baseline value.

Economic impacts were similarly calculated. First, the average annual value of each economic indicator was calculated by taking the average of the 30- or 35-yr simulation output from FEM for each farm. Then the farm-level annual averages were summed using all farms in the watershed of interest to obtain watershed-level annual averages. This computation was performed for each scenario and for a number of economic indicators, although the main economic indicator was net farm returns. Then the annual average values were divided by the total farmland area in hectares among all the representative farms to arrive at per hectare values for the economic indicators. Finally, economic impacts for each scenario were computed as the difference between the baseline per hectare value (mainly net farm returns) and the corresponding per hectare value for the same indicator for each scenario.

The fact that the results presented here are average annual impacts for each simulated scenario and each environmental and economic indicator relative to baseline simulations implies a number of things. First, the magnitude of the impacts for any given year may be different from the average impacts. In fact, the impact for any given year may be of the opposite effect to that indicated by the average value. This is particularly true for the environmental impacts, which are dependent upon weather patterns, but also true for the economic impacts.

Secondly, the impacts do not depict any dynamic patterns or trends with time and do not answer questions related to dynamics or trends of indicators. This means these results do not indicate how many years it will take to reach a desired target. They simply indicate the relative impact of each scenario for an average year, and an average year may never be observed. Dynamic patterns and trends may be gleaned from the annual results of the model simulations but were not discussed in this report.

Thirdly, the actual or simulated impacts also differ spatially. This means the results were different from one area of the watershed to another. As with the dynamic patterns, the impact of a scenario for a given location may also be different from the average impact presented for that scenario at the outlet of the watershed. Scenario impacts are presented at the sub-basin level in more detail in Appendices 2 to 6. However, the impacts of specific fields within each sub-basin are also likely to differ and these results are not presented in this report. For the economic indicators, the scenario impacts differ from one farm to another. As well, the simulated farm-level scenario impacts presented in this report are for representative farms. While representative farms are by definition representative of the farms in the watershed, they are not identical to actual farms in each watershed.

Plotting the environmental and economic impacts on a graph shows the trade-offs between environmental improvements (E) and changes in farm profits ($) (Figures 5.3). The horizontal axis in each of the figures corresponds to farm profits, with regions to the left of the vertical axis representing reductions in profit, while regions to the right of the vertical axis represent improvements in farm profits for the selected scenario. Similarly, regions above the horizontal axis represent percentage increases in an environmental indicator, while regions below the horizontal axis represent percentage reductions (or improvements) in the environmental indicator. A scenario is superior to another if it lies below and to the right of the other. For example, in Figure 5.3, Scenario D is superior to the other three scenarios.

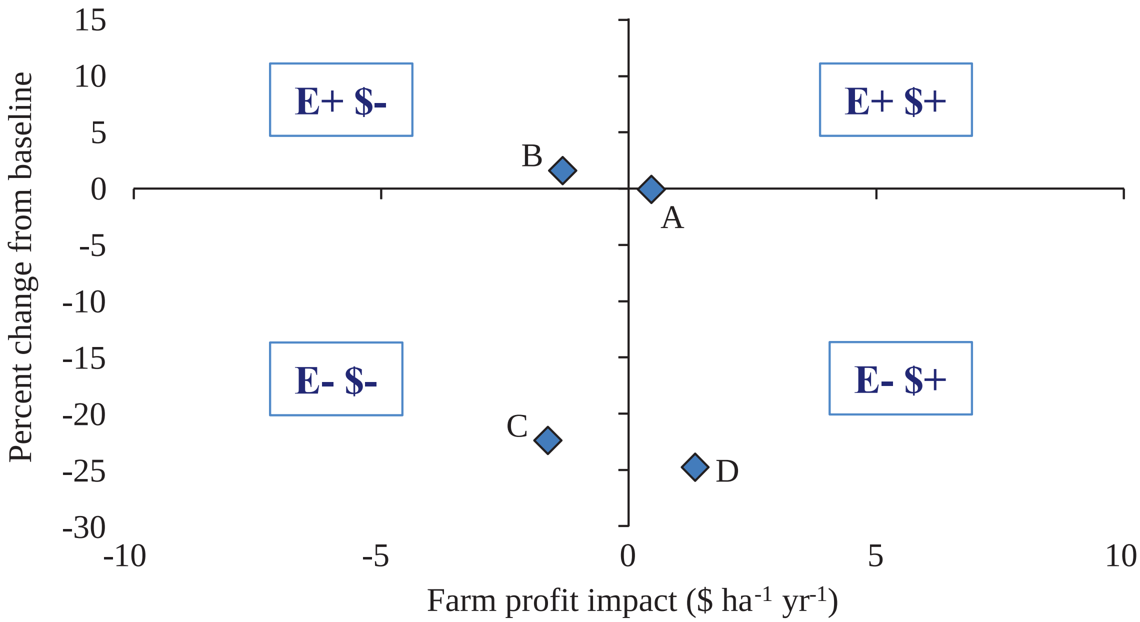


Figure 5.3. Schematic of the CEEOT model output showing environmental and economic impacts of simulated scenarios, where A, B, C, and D each represent a scenario of BMPs.

5.4 Results and Discussion of Scenario Simulations

5.4.1 Baseline Scenarios for IFC, WHC, and LLB

The sub-basin scale results showed high variability in average annual runoff depths and in average annual TSS and nutrient losses within each watershed. For example, in IFC, CEEOT predicted average annual runoff depths ranged from 14 mm in Sub-basins 2, 3, and 23 to 205 mm in Sub-basin 5 (Appendix 2). The predicted maximum average TSS loss was 5.43 Mg ha^{-1} in Sub-basin 5 and the maximum average TN and TP loss were 18.8 and 3.7 kg ha^{-1} in Sub-basin 27, respectively. Generally, higher runoff depths resulted in higher TSS and nutrients losses (Sub-basins 5 and 27). An exception was Sub-basin 19 where the average runoff depth of 90 mm generated relatively high average nutrient loss (5.5 kg ha^{-1} NO_3-N and 2.0 kg ha^{-1} PO_4-P) when compared to 118 mm runoff depth in Sub-basin 22 (2.6 kg ha^{-1} NO_3-N and 0.5 kg ha^{-1} PO_4-P). This result may be attributed to the effects of manure spreading near the drainage channel at the SMF site and the influences of the cattle pasture/calving area in Sub-basin 18. The average STP concentration in the soil measured during the field study was slightly above the agronomic threshold of 60 mg kg^{-1} and this suggests that excessive amounts of manure had not been applied in recent years.

In WHC and LLB, the sub-basin scale average annual runoff depths, and average annual sediment and nutrients losses were much lower compared to IFC (Appendices 3, 4). In WHC, runoff depths ranged from 0.5 mm (Sub-basin 5) to 80 mm (Sub-basin 19). The maximum sediment loss of 0.019 Mg ha^{-1} was in Sub-basin 19, the maximum TN loss of 0.74 kg ha^{-1} was in Sub-basin 9, and the maximum TP loss of 0.46 kg ha^{-1} was in Sub-basin 14. For LLB, the average runoff depth of 22 mm was predicted for both sub-basins (Appendix 4). Sediment loss ranged from 0 to 0.019 Mg ha^{-1}, TN loss ranged from 0.97 to 1.25 kg ha^{-1}, and TP loss ranged from 0.35 to 0.42 kg ha^{-1}. Sediment and nutrients losses were larger in Sub-basin 1 due to the greater slopes of tributary channels.

A comparison of the watershed-wide simulation results indicated that IFC had nearly five times higher runoff potential (99 mm) than WHC (19 mm) and LLB (22 mm) (Table 5.5). In addition, IFC average sediment losses were predicted to be more than 140 times higher when compared to WHC and LLB sediment losses. High runoff and sediment loss potential also resulted in high N and P losses. For example, IFC TN losses were more than six times higher than LLB losses, and more than 37 times higher than WHC losses. The IFC TP losses were more than three and nine times higher than LLB and WHC losses, respectively. The model also predicted 62% higher PO_4-P losses in IFC than in LLB even though the IFC STP values were nearly five times lower than the LLB STP values (ARD 2014). Under similar WHC and LLB runoff potential, the simulation results suggest TN and TP losses were nearly five and three times higher at the LLB site than at the WHC Sub-watershed, respectively (Table 5.5). Higher TN and TP losses at the LLB site can be related to the high STP values in the soil. These results suggest that high runoff potential in IFC is a dominate factor that controls sediment and nutrient loss in the watershed. However, the high soil nutrient concentrations cause larger nutrient losses at the LLB site than at WHC.

Table 5.5. Comparison of baseline scenario annual average runoff depths, and TSS and nutrient losses for the Indianfarm Creek Watershed (IFC), Whelp Creek Sub-watershed (WHC), and Lower Little Bow River Field (LLB).

Watershed	Runoff (mm)[z]	TSS ($Mg\ ha^{-1}$)	ON	OP	NO_3-N	PO_4-P	TN	TP
			($kg\ ha^{-1}$)					
IFC	99 (82)	1.40	4.96	0.86	2.97	0.65	7.93	1.51
WHC	18 (8)	0.002	0.16	0.06	0.05	0.11	0.21	0.16
LLB	22 (23)	0.01	0.03	0.02	1.23	0.40	1.25	0.42

[z] Values in brackets are measured average annual runoff depths during 2007 to 2010 for IFC and during 2008 to 2010 for WHC and LLB.

5.4.2 Alternative Scenarios for the Indianfarm Creek Watershed

5.4.2.1 Scenario 2 (Field Study) Simulation

At the subarea scale, it was predicted that changes in flow and nutrient losses would occur for Scenario 2 when compared to the baseline. With few exceptions, nearly all subareas with a BMP site had reductions in flow and TSS and nutrient losses (Table 5.6). Subareas 970 and 971 for the PST BMP were notable exceptions where the BMP resulted in increased nutrient and sediment losses and runoff volumes. In these two subareas, the baseline entailed an alfalfa-oat rotation; whereas, for the BMP scenario a continuous rotational pasture land use was implemented, to reflect the BMP-implementation plan. While it may be difficult to conceive of the increase in sediment and nutrient losses as a result of the rotation change, the only differences simulated between the two scenarios were the change in rotation and the timing of livestock grazing on those subareas. Thus the increase in sediment and nutrient losses is likely due to an interplay of change in crop cover and livestock grazing schedules along with the specific biophysical properties (weather, soils, topography) of those subareas. Due to the very small size of these subareas it is recommended that the impacts be interpreted restrictively and not generalized for other areas with similar rotations and grazing schedules.

The weighted averages of flow and nutrient losses for the BMP sites showed that nearly all sites were reduced in Scenario 2 relative to the baseline values, except for the PST site (Table 5.6). Annual flow reductions were small (< 2%) for the NMF and SMF sites, with a slight (1%) increase in flow at the PST site. The flow reductions were greater at the DMF (12%), IMP (4%), and WIN (5%) sites. Based on the BMPs for these three sites, it is unclear what mechanisms would be responsible for flow reduction. The elimination of manure application at the DMF site, exclusion of cattle from the IMP water body, and relocation of the wintering site were not designed to alter flow. However, with cattle exclusion, perhaps improved vegetation cover around the impoundment reduced flow into the impoundment. On the other hand, nearly all of the water that flows through the impoundment originates from a large area upstream (Sub-basin 23; Figure 2.3) and this area was not influenced by the IMP BMPs.

Table 5.6. Percentage change for Scenario 2 relative to the baseline scenario for flow, total suspended solids (TSS), and nitrogen and phosphorus fractions for the BMP sites in the Indianfarm Creek Watershed.

BMP site	Subarea ID	Subarea size (ha)	Subbasin ID	Flow	TSS[z]	TN	TP	ON	OP	NO_3-N	PO_4-P
				(%)							
				Per subarea							
DMF	116	13.8	4	-12.5[y]	-8.3	-12.4	-19.1	-15.8	-18.6	-4.5	-20.0
DMF	130	2.3	4	-11.7	-8.8	-16.5	-25.8	-22.4	-25.6	-3.9	-26.1
DMF	390	1.4	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IMP	960	2.6	2	-8.5	-7.9	-12.0	-21.1	-26.2	-28.1	-4.8	-9.1
IMP	2400	0.4	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IMP	104	2.0	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NMF	1401	2.8	6	-0.6	0.0	-4.9	-26.9	-4.6	-20.3	-5.1	-32.1
NMF	299	3.1	6	-0.3	0.0	-1.2	-10.0	-0.9	-7.0	-1.5	-14.0
NMF	358	2.2	6	-0.5	6.3	-1.5	-16.8	0.0	-11.8	-3.1	-22.4
NMF	327	1.8	6	-1.2	0	-7.7	-49.6	-3.1	-57.1	-12.3	-45.2
NMF	9	15.8	6	-0.6	16.7	-3.7	-25.9	-2.5	-20.0	-4.7	-30.5
NMF	319	40.0	6	-0.7	33.3	-6.8	-39.5	-4.3	-33.3	-8.9	-43.6
PST	313	2.2	10	-60.2	-25.0	-60.5	-71.0	-77.1	-23.7	-36.7	-90.3
PST	968	3.4	10	-4.0	-3.4	29.7	-3.3	-10.7	13.0	174.2	-25.5
PST	183	12.9	1	-0.7	0.0	2.7	-1.5	4.1	-2.0	1.6	0.0
PST	316	2.1	1	-0.8	-2.4	-6.1	-6.7	-7.0	-6.0	-3.5	-9.5
PST	972	14.2	1	-0.7	0	2.3	-2.8	2.8	-3.8	1.9	0.0
PST	309	5.5	1	-3.5	11.1	10.6	1.2	3.7	0.0	16.3	3.4
PST	197	19.0	1	-0.7	0.6	13.1	5.0	47.8	4.0	2.9	6.7
PST	180	0.6	7	6.8	-52.2	-71.5	-81.2	-80.4	-79.2	-51.1	-87.3
PST	967	6.7	7	7.9	-52.3	-73.2	-82.7	-80.7	-79.9	-54.9	-92.7
PST	970	4.0	8	63.6	77.1	257.1	154.2	208.7	215.7	402.5	83.6
PST	196	3.2	8	29.0	33.3	153.1	40.5	-22.2	71.4	287.6	30.7
PST	314	0.6	9	-0.7	11.1	-19.5	-49.1	-23.8	-53.8	-17.3	-47.5
PST	969	0.7	9	-0.7	18.2	-20.6	-50.0	-25.6	-53.8	-17.9	-48.8
PST	971	5.3	11	38.7	211.5	368.5	245.4	464.1	289.7	139.8	105.9
SMF	714	6.2	19	-1.7	0.0	-22.2	-41.0	-16.7	-16.9	-23.5	-54.8
WIN	332	0.5	9	-26.7	-75.0	-94.0	-50.0	-66.7	0.0	-94.3	-57.1
WIN	975	0.9	13	-0.8	3.4	-2.1	-2.4	-2.1	-5.1	-2.1	-1.1
WIN	993	7.4	13	-13.9	-31.7	-44.0	-35.9	-51.7	-47.9	-15.3	-16.9
WIN	1400	0.2	13	-14.0	-32.5	-44.0	-35.7	-51.7	-47.2	-15.3	-17.0
WIN	989	26.99	14	-0.2	0.0	-0.4	-2.3	-0.6	-3.2	0.0	0.0
WIN	991	1.1	11	0.0	0.0	-0.8	-2.1	-2.2	-1.9	0.0	-2.4
WIN	993	7.4	13	-13.9	-31.7	-44.0	-35.9	-51.7	-47.9	-15.3	-16.9
WIN	994	5.2	24	0.2	0.0	-8.1	0.0	0.1	0.8	-24.9	-3.3
WIN	995	6.32	14	0.0	0.0	-0.7	0.0	-0.5	0.0	-1.0	0.0
WIN	998	3.4	11	0.0	0.0	0.1	0.0	0.0	0.0	0.6	0.0
WIN	999	3.5	12	0.0	0.0	-0.1	-0.9	-0.1	0.0	-0.4	-3.7
WIN	1000	5.5	24	0.0	-2.6	-13.3	-0.9	-0.7	0.0	-29.5	-3.7

Table 5.6. Continued.

BMP site	Subarea ID	Subarea size (ha)	Subbasin ID	Flow	TSS[z]	TN	TP	ON	OP	NO_3-N	PO_4-P
				(%)							
Weighted average per BMP site											
DMF		17.5		-11.9	-8.3	-12.7	-19.9	-16.6	-19.4	-4.2	-20.6
IMP		5.0		-4.2	-3.5	-6.1	-12.1	-14.0	-16.8	-2.4	-4.8
NMF		65.7		-0.6	17.4	-5.0	-32.5	-3.2	-25.9	-6.6	-37.4
PST		80.4		1.3	0.6	-5.6	-23.9	-8.7	-20.8	-1.0	-31.3
SMF		6.2		-1.7	0.0	-22.2	-41.0	-16.7	-16.9	-23.5	-54.8
WIN		68.4		-4.7	-8.3	-17.5	-14.7	-18.0	-16.8	-16.0	-9.7

[z] TSS = total suspended solids, TN = total nitrogen, TP = total phosphorus, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus.
[y] A negative percentage means the Scenario 2 value was less than the baseline scenario value.

For most of the BMPs, the reduction in P fractions was generally greater than for N fractions (Table 5.6). In the case of the PST site, N and P fractions were reduced; whereas, flow and TSS were increased in Scenario 2. In addition, it was predicted that the NMF and SMF sites would have a reduction of TP losses by about 33 and 41% on average, respectively. However, the IMP and WIN sites were predicted with smaller (12 and15%, respectively) reductions of TP.

Attempts to compare the simulated BMP impacts to measured impacts in the field were not successful primarily because the duration of available measured data was too short to correct for weather impacts. Specifically, the BMP sites had been installed for only a few years and the measured impacts were heavily skewed by changes in weather that occurred between 2007 and 2010, as reflected in significant differences in measured flow volumes from year to year (ARD 2014).

There was a wide range of BMP implementation costs among the BMP sites (Table 5.7). Most of the costs occurred at the time of implementation. However, some BMP costs were continuous, such as annual soil sampling and analysis, and these were modelled for all simulation years.

The BMP project costs listed in Table 5.7 were applied as a new capital investment in FEM and were then amortized for a 7-year period. For the six farms with BMP sites, the net economic impact of the BMPs was a reduction in net return ranging from \$0.01 to just over \$8 ha^{-1} yr^{-1} (Table 5.8). Although the change in average annual net returns during the simulation period varied considerably among BMP sites, much of the difference in change in net return per hectare stems from the even larger variation in the size of the farms that implemented the BMPs. For example, the reduction in annual net returns for the SMF farm was more than six times that of the WIN farm, but expressed on a per hectare basis, the reduction was actually smaller. Larger farms translate into lower costs per hectare when assessed at the farm level.

Table 5.7. Summary of the beneficial management practices (BMP) implementation costs for Scenario 2 (field study BMPs) for Indianfarm Creek Watershed.[z]					
BMP site	Farm size (ha)	Materials and contracts ($)	Labour ($)	Total capital cost ($)	Annual BMP cost (e.g., soil testing) ($ yr^{-1})
IMP	1,018	17,512	360	17,872	0
PST	310	16,643	2,960	19,603	0
WIN	192	15,490	1,220	16,710	0
SMF	1,514	2,530	0	2,530	306
NMF	12,376[y]	822	160	982	0
DMF	268	0	0	0	203

[z] These are BMP implementation costs incurred by the farms as reported in the 2010 Progress Report (Olson and Kalischuk 2011). The bioengineering costs at the IMP, WIN, and PST sites were not included.
[y] This farm size is based on the area owned (3237 ha) and rented (12,950 ha) by the farmer, as reported in the producer survey. Some of this land area may be outside IFC Watershed.

Table 5.8. Summary of the Farm-level Economic Model annual economic results simulated for Scenario 2 (field study BMPs) relative to Scenario 1 (baseline) for Indianfarm Creek Watershed.[z]						
	Change in annual farm cost				Change in net return	
BMP site	Variable ($ yr^{-1})	Capital ($ yr^{-1})	Total cost ($ yr^{-1})	Total cost ($ ha^{-1} yr^{-1})	Total net return ($ yr^{-1})	Total net return ($ $ha^{-1}yr^{-1}$)
IMP	-228	-193	-421	-0.41	-769	-0.76
PST	686	1,161	1,847	5.95	-1,847	-5.95
WIN	585	990	1,575	8.19	-1,575	-8.19
SMF	793	-1,611	-818	-0.54	-12,007	-7.93
NMF	34	58	93	0.01	-93	-0.01
DMF	232	0	232	0.87	-255	-0.84

[z] Negative numbers indicate a reduction in value relative to the baseline; positive numbers indicate an increase relative to the baseline.

The model results at the watershed outlet for Scenario 2 showed much smaller environmental impacts compared to the BMP sites. Again, this is due to the small total area of the BMPs compared to the overall watershed. At this scale, the model predicted that Scenario 2 (field study BMPs) would reduce NO_3-N loss by about 4% and PO_4-P loss by about 2% at the outlet during a 30-yr period (Table 5.9). To a lesser extent (< 2%), TN and TP losses would also be reduced. Organic N and OP losses would only be affected slightly and TSS loss and flow would not be affected by Scenario 2. These results suggest that most of the reduction in N and P would be caused by a reduction in the concentration of the soluble forms of these two nutrients. The small changes may reflect that the field study BMPs in Scenario 2 only represented six sites in the whole watershed and the vast majority of the watershed was not simulated with BMPs. The reduction in the annual farm profits (net returns) per hectare of the field study BMPs, averaged for the entire watershed, was estimated at \$0.92 ha^{-1} yr^{-1} (Table 5.9). This reduction in net returns reflects a decline in revenues and/or increase in costs. The decline in average revenues, primarily through reductions in harvested crop area or productivity, was about \$0.77 ha^{-1} yr^{-1} on average, while the increase in costs was about \$0.15 ha^{-1} yr^{-1}.

Table 5.9. Annual average environmental and economic results based on 30 -yr simulation for the outlet of Indianfarm Creek Watershed for different scenarios.

	Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP	Net return
					Predicted values				
Scenario[z]	($m^3\ s^{-1}$)	(Mg yr^{-1})	(kg yr^{-1})						(\$1,000 yr^{-1})
Scenario 1	0.443	19,833	70,158	12,191	41,978	9,212	112,137	21,403	7,649
Scenario 2	0.444	19,828	69,934	12,143	40,243	9,001	110,178	21,145	7,633
Scenario 3	0.443	19,830	69,277	12,152	41,963	9,096	111,240	21,248	7,643
Scenario 4	0.408	14,914	7,430	2,430	36,802	8,714	44,232	11,144	7,620
Scenario 5	0.408	14,911	7,423	2,432	36,798	8,561	44,221	10,992	7,360
					Change relative to baseline (Scenario 1)[y]				
	(%)								(\$ $ha^{-1}\ yr^{-1}$)
Scenario 2	0.0	0.0	-0.3	-0.4	-4.1	-2.3	-1.8	-1.2	-0.92
Scenario 3	0.0	0.0	-1.3	-0.3	0.0	-1.3	-0.8	-0.7	-0.34
Scenario 4	-8.1	-24.8	-89.4	-80.1	-12.3	-5.4	-60.6	-47.9	-1.65
Scenario 5	-8.1	-24.8	-89.4	-80.1	-12.3	-7.1	-60.6	-48.6	-16.14

[z] Scenario 1 = baseline; Scenario 2 = field study BMPs; Scenario 3 = AOPA management practices; Scenarios 4 and 5 = alternative scenarios.
[y] Differences for Scenarios 2 to 5 are expressed relative to Scenario 1 (baseline). Negative numbers indicate a decrease compared to the baseline.

5.4.2.2 Scenario 3 (AOPA) Simulation

Scenario 3, when simulated on all applicable farms in the watershed, had little impact at the outlet of IFC Watershed. The model predicted about a 1% reduction in PO_4-P loss and a 1% reduction in ON loss (Table 5.9). Total N and TP losses were predicted to decline by less than 1% each. Flow, TSS loss, and NO_3-N loss were predicted not to change. On average, Scenario 3 was projected to result in a \$0.34 $ha^{-1}\ yr^{-1}$ reduction in net farm returns in IFC. Economic impacts for individual farms are reported in Appendix 5 for Scenario 3. For individual representative farms, changes in net returns ranged from a reduction of about \$4.37 ha^{-1} to an increase of about \$1.75 ha^{-1}.

The predictions from Scenario 3 suggest that the management of manure application, based on NO_3-N limits through AOPA, was not much different to manure application practices prior to when AOPA did not have confined feeding operation and manure management regulations. This is not surprising because the model predicted that none of the subareas ever reached the soil NO_3-N limit for this area of 225 kg ha^{-1} (Table 5.3), which is required to trigger manure application constraints. The maximum predicted soil NO_3-N was about 44 kg ha^{-1} in the fourth year of the simulation (Figure 5.4), and this was for Subarea 973 in the south portion of Sub-basin 9 (Figure 2.3). Actual soil-test N measured at the DMF, NMF, SMF, and REF sites during the field study was well below the AOPA NO_3-N limits, and this was likely true for the whole watershed. In addition, less than 15%, or slightly more than 2000 ha, of the total land base in IFC was predicted to receive manure application (Table 5.10).

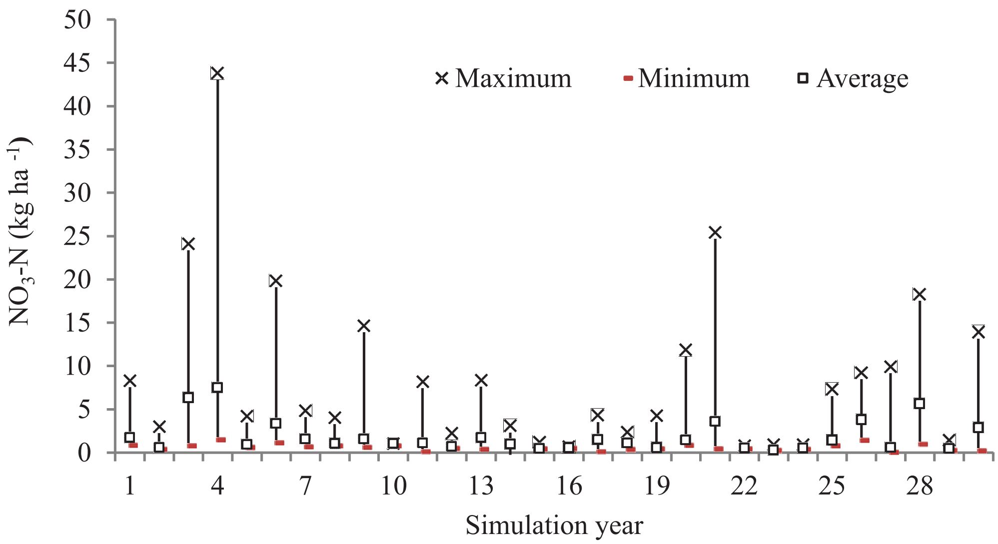


Figure 5.4. Predicted minimum, maximum, and average soil nitrate nitrogen (NO_3-N) levels among the subareas for each simulation year for 30 yr in the Indianfarm Creek Watershed, as simulated during Scenario 3.

The predictions from Scenario 3 in IFC also suggest that the use of setbacks of no manure application alongside common water bodies had little effect on the IFC Watershed. The land base used for manure application in Scenario 3 was only 2% less compared to Scenario 1 (baseline) (Table 5.10; Appendix 6). This decrease was due to the establishment of setbacks that excluded manure application. This reduction represented less than 0.4% of the total land base in IFC Watershed. While the setbacks represent only a 2% reduction in the land area that received manure in the scenario, this area was in critical source areas near common water bodies. However, the mainstem, as well as the main tributaries, have riparian zones wide enough so that 30-m or wider

Table 5.10. Manure application rates and water setbacks for modelled BMP scenarios in the Indianfarm Creek (IFC) Watershed.

	Manure application			Land base for BMPs		
	Landbase[y]	Manure N	Manure P	Setback	Grass waterway	Buffer strip
Scenario[z]	(ha)	--------- (kg yr^{-1}) ----------		--------------------- (ha) ---------------------		
Scenario 1	2,060	164,015	48,392	0	0	0
Scenario 2	2,055	163,287	48,244	na[x]	0	0
Scenario 3	2,013	160,391	47,362	47	0	0
Scenario 4	1,980	157,626	46,520	47	192	126
Scenario 5	2,027	99,664	21,196	47	192	126

[z] Scenario 1 = current application practises; Scenario 2 = implementation of field study BMPs; Scenario 3 = manure application is N-based with AOPA setbacks ; Scenarios 4 = Scenario 3 practises with the addition of riparian buffers and grassed waterways; and Scenario 5 = manure application is P-based and spring applied.
[y] Total land base in IFC is 14,145 ha.
[x] Not applicable.

setbacks would not be required on adjacent manured fields. Plus, the smaller drainage channels in and near fields where setbacks could be applied would likely only generate a very small percentage of the total runoff. Also, as indicated above, the soils in the IFC Watershed did not seem to have an excessive accumulation of nutrients from manure application.

5.4.2.3 Scenario 4 (Cow-calf) Simulation

Scenario 4 is the first scenario to show large reductions in all environmental indicators (Table 5.9). This scenario augments Scenario 3 (AOPA) with grazing management and riparian conservation practices. In addition, the area of manure N and P (kg yr^{-1}) land application in Scenario 4 was reduced by 4% compared to Scenario 1 (baseline) (Table 5.10; Appendix 6). The model assumed a reduction in land available for manure applications in Scenario 4 compared to Scenario 3 because in addition to the setbacks required in Scenario 3, additional land area was used for buffer strips and grassed waterways in Scenario 4, which also excluded manure application from these areas.

The model predicted reductions of about 61% of TN and 49% of TP at the watershed outlet compared to the baseline (Table 5.9). Even larger reductions (>80%) in ON and OP losses were predicted. Flow and TSS losses were also predicted to decline by about 8 and 25% from baseline, respectively. The reduction in flow would result in loss reduction even if concentration remained similar. A reduction in TSS loss would result in reduced particulate nutrient loss such as ON and OP. The application of rotational grazing and riparian BMPs would likely help stabilize stream banks and reduce erosion and sediment loss. This scenario was estimated to cost \$1.65 ha^{-1} annually throughout the watershed (Table 5.9), with a range of about \$0.06 to \$17.48 ha^{-1} (Appendix 5). Compared to Scenario 3 (AOPA), the cattle restriction to water bodies and application of grazing management, grass waterways and buffer strips had a much larger positive environmental effect compared to the application of NO_3-N limits and setbacks through AOPA. This would suggest that grazing management improvements, better protection of riparian areas, and implementation of grass waterways would be more effective than additional manure management BMPs for this particular watershed. This seems reasonable for IFC since most of the northern portion of the watershed is cultivated land and a majority of livestock activity occurs in the riparian areas. The southern portion of the watershed is predominantly grassland and there is cow-calf activity throughout. As indicated above, it is predicted that less than 15% of the watershed area receives manure application, which corresponds with the three feedlots in IFC. As a result, manure management may not be as applicable to IFC as compared to other agriculture watersheds that have a greater concentration of confined feeding operations, which are associated with manure application.

5.4.2.4 Scenario 5 (P-limit) Simulation

Scenario 5 showed nearly the same environmental impacts as Scenario 4, except that PO_4-P and TP losses were reduced slightly more in Scenario 5 (Table 5.9). Scenario 5 includes Scenario 4 BMPs with the addition of agronomic P-based manure application rates and application restricted to spring and summer periods. As mentioned in Scenario 4, it is predicted that less than 15% of the watershed area receives manure application and hence, the practise is applied to a very small portion of the watershed. These predictions suggest that in the IFC Watershed P-based application of manure would only result in a small improvement in water quality. Results were further validated during the field study, where STP results measured at four of the field study BMP sites (NMF, SMF, DMF, and REF sites) were less than 100 mg kg^{-1} in the top 15 cm and often less than the agronomic threshold of 60 mg kg^{-1} (ARD 2014).

Unlike the relatively low costs associated with Scenarios 2, 3, and 4, Scenario 5 was projected to cost about \$16 $ha^{-1}yr^{-1}$ relative to the baseline (Table 5.9), expressed per hectare of owned and leased farmland in the watershed. The substantial increase in cost was primarily due to the increase in manure hauling costs because more land was required to accommodate P-based manure application, and part of the land was also used for buffer strips, wetlands, and waterways required in this scenario. Where the land base does not change significantly for the environmental simulations, the cost increase was due to the fact that manure was exported off the farm, at an assumed hauling distance of 8 km, and hence entailed a significant cost to the producer. The change in net returns for individual representative farms ranged from an increase in returns of about \$3.5 $ha^{-1}yr^{-1}$ to a decline of about \$213 $ha^{-1}yr^{-1}$ (Appendix 5). Unlike the economic simulations, the environmental models did not distinguish between manure application fields in terms of land ownership and implicitly assumed that the manure was hauled out of the watershed.

5.4.2.5 Cost Effectiveness of BMP Scenarios

A graphical comparison of environmental indicator (TSS, flow, TN, or TP) change and farm profit impact shows very little change in the four environmental indictors for Scenarios 2 (field study BMPs) and Scenario 3 (AOPA) at a watershed scale (Figure 5.5a, b, c, d). In contrast, Scenarios 4 (cow-calf) and 5 (P-limit) resulted in decreases in all four indicators. In terms of farm profit, Scenarios 2 to 4 were similar to the baseline, with each registering a slight reduction in net returns. It is clear that Scenario 4 resulted in almost the same reductions in the environmental indicators as Scenario 5, but at much lower cost.

One way to approach cost-effectiveness is how much it costs to obtain one unit improvement in an environmental indicator. When expressed as the cost per unit of environmental indicator change, Scenario 4 is more cost effective than Scenarios 2 and 5. For example, while the cost was less than \$5 Mg^{-1} of TSS reduced with Scenario 4, the same amount of TSS reduction cost more than ten times (over \$52 Mg^{-1}) with Scenario 5 (Table 5.11). Scenario 3 (AOPA) resulted in a small improvement in farm profits, and as a result, most of the cost-effectiveness values associated with Scenario 3 were negative.

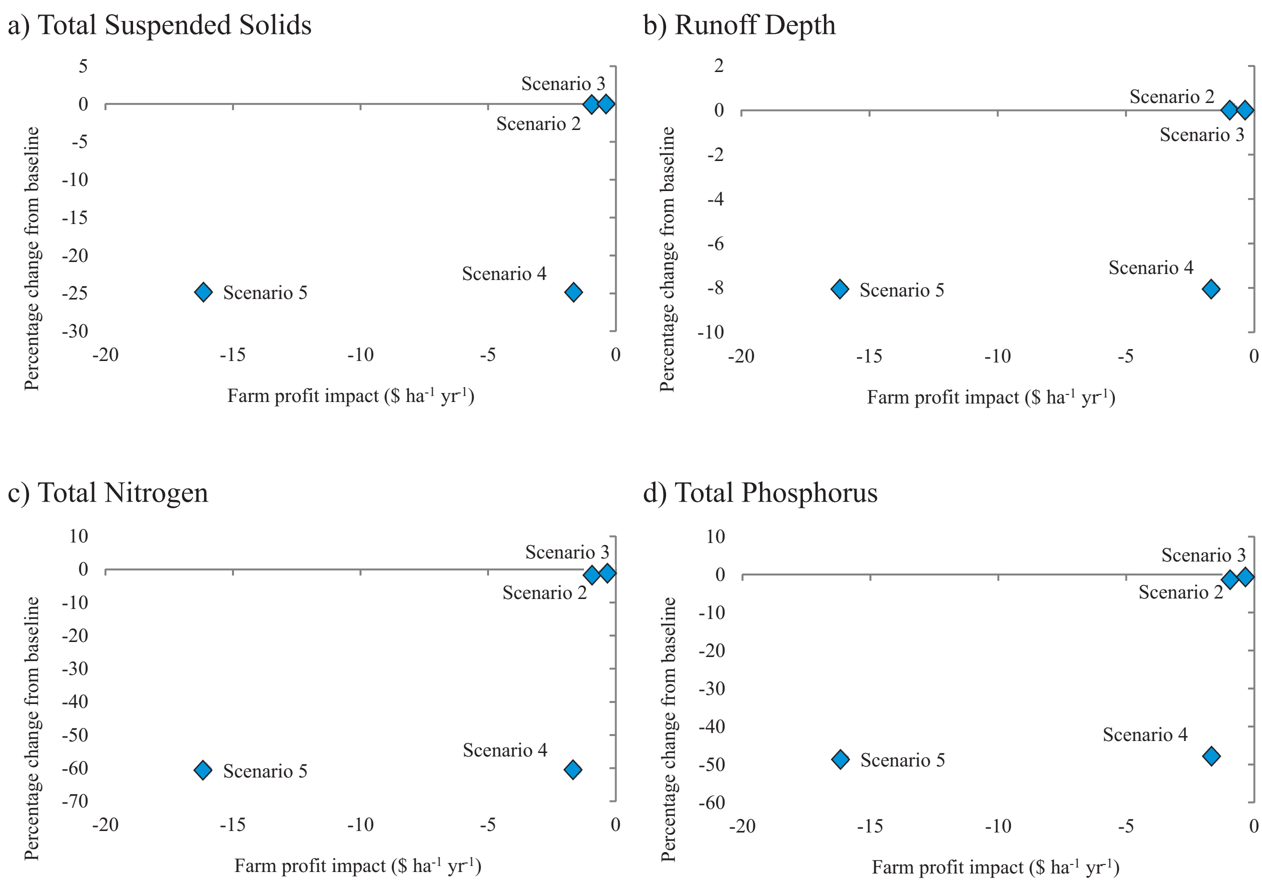


Figure 5.5. Impacts of scenarios on farm profits and (a) total suspended solids losses, (b) runoff depth, (c) total nitrogen losses, and (d) total phosphorus losses for Indianfarm Creek Watershed.

Table 5.11. Cost effectiveness of alternative scenarios for the Indianfarm Creek Watershed.

Scenario[z]	Flow ($ m^{-3})[y]	TSS ($ Mg^{-1})	Organic N	Organic P	NO_3-N	PO_4-P	Total N	Total P
			($ kg^{-1})					
Scenario 2	-3.49	3,478.64	83.15	393.39	10.74	88.58	9.51	72.30
Scenario 3	-1.26	-1,998.82	-7.23	-163.06	-414.61	-55.04	-7.11	-41.15
Scenario 4	0.02	4.82	0.38	2.43	4.58	47.67	0.35	2.31
Scenario 5	0.23	52.49	4.12	26.47	49.86	396.55	3.80	24.81

[z] Scenario 1 = baseline; Scenario 2 = field study BMPs; Scenario 3 = AOPA manage ment practices; Scenarios 4 and 5 = alternative scenarios.
[y] negative values indicate.

5.4.3 Alternative Scenarios for the Whelp Creek Sub-watershed

5.4.3.1 Scenario 2 Simulation

Since the BMPs were installed on relatively small sites, the field-scale impacts determined with the APEX model provide better insights into their relative effectiveness than the model results at the outlet. Values of key indicators for baseline and BMP site simulations are presented in Appendix 3 (Table A3.5). The weighted averages of the subareas containing the BMPs showed that some BMPs were more effective than others for most or all of the environmental indicators (Table 5.12). For instance, the EFD and SPS sites were projected to reduce TP losses by about 28 and 26% on average, respectively. However, the SFD and WFD sites were predicted to have very minimal impacts on the environmental indicators. For example, Subarea 5101 at the WFD site had no effect on the indicators, largely due to the fact that the size of Subarea 5101 was very small compared to the upslope field. Furthermore, there was limited biomass growth on the setback area due to the reduced nutrient application on that area, and this increased flow rate and sediment losses.

A major reason for the minimal impacts from SFD and WFD may be attributed to the fact that these two sites had very small flow and sediment and nutrient losses in the baseline. Consequently, any changes caused by the BMP implementations would be within the margin of error of the field scale model simulations. For instance, baseline predicted sediment loss for subarea 5501 of SFD was 0.01 Mg ha^{-1} while it was 0.0 Mg ha^{-1} under the BMP scenario. This is represented correctly as a 100% reduction, but the absolute magnitudes are clearly very small.

The implementation costs for the BMP sites in WHC were relatively low, i.e., <$5,000 (Table 5.13). However, the annual BMP manure and soil testing costs for two of the BMP sites were about $1,000 yr^{-1} or more. The FEM simulation results showed that the average annual costs of the BMPs (reduction in net returns) ranged from $4.53 to $35.86 ha^{-1} yr^{-1} relative to Scenario 1 (Table 5.14).

At the watershed scale, the results obtained for the WHC Sub-watershed were different from those obtained for the IFC Watershed. The model simulations predicted that Scenario 2 (Field Study BMPs) would have a larger impact in WHC Sub-watershed than in IFC Watershed. Total suspended solids were reduced by 0.9% and N and P parameters were reduced from 2.9 to 8.9% (Table 5.15). There was a negligible reduction in flow; however, this was not surprising since the BMPs simulated in the model were not designed to reduce runoff volume. Both watersheds had similar numbers of field study BMPs; however, WHC Sub-watershed is about one-third the size of IFC Watershed. Therefore, a similar number of BMP sites in WHC may potentially have a larger effect on a smaller watershed. Also, the difference in types and distribution of BMP sites within the two watersheds may be factors. The field study BMPs in WHC were mainly nutrient management BMPs in annually cropped fields; whereas, cattle grazing and riparian management were the main BMPs implemented in IFC.

Economic impacts at the watershed level showed a cost slightly greater than $4 ha^{-1} yr^{-1}, which is an annual average among all farms within the watershed and for all simulation years (Table 5.15).

Table 5.12. Percentage change for Scenario 2 relative to the baseline scenario for flow, total suspended solids (TSS), and nitrogen and phosphors fractions for the BMP sites in the Whelp Creek Sub-watershed.

BMP site	Sub-area ID	Subarea Size (ha)	Sub-basin ID	Flow	TSS	TN	TP	ON	OP	NO_3-N	PO_4-P
				----	----	----	----	(%)	----	----	----
						Per subarea					
EFD	1297	0.5	5	1.1	0.0	-99.3	-91.2	-100	-100	0.0	-90.6
EFD	1311	2.5	5	1.2	0.0	-51.2	-41.5	-51.3	-50.0	0.0	-41.1
EFD	5000	3.1	5	0.4	0.0	-11.9	-10.7	-12.0	0.0	0.0	-11.0
NFD	415	1.1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NFD	424	0.6	1	0.0	0.0	0.0	-5.9	0.0	0.0	0.0	-8.3
NFD	432	0.7	3	0.6	0.0	-35.7	-9.1	-83.3	0.0	0.0	-11.1
NFD	604	3.1	3	0.6	0.0	-16.7	-12.5	-21.4	-50.0	0.0	0.0
NFD	419	1.1	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NPS	934	0.4	17	-7.7	0.0	-71.0	-50.0	-90.5	-50.0	-30.0	-50.0
NPS	940	3.2	17	-9.1	0.0	-21.5	-14.6	-22.0	-23.5	-18.2	-13.5
NPS	2400	0.04	17	5.7	0.0	-83.3	0.0	0.0	0.0	-83.3	0.0
NPS	748	1.2	17	-15.2	0.0	-28.8	-24.5	-29.5	-33.3	-16.7	-23.6
NPS	927	0.2	17	-12.4	0.0	-26.1	-18.3	-26.8	-31.3	-16.7	-16.8
NPS	2401	0.8	17	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SFD	5500	0.8	10	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SFD	5501	0.2	10	3.5	-100	0.0	0.0	0.0	0.0	0.0	0.0
SFD	1918	18.5	10	-0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SFD	1909	26.0	10	-0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPS	2717	3.7	13	2.5	0.0	0.3	-3.6	-0.2	-4.1	100	0.0
SPS	2719	9.9	14	-13.5	0.0	-12.3	-26.0	-7.8	-24.4	-37.5	-27.4
SPS	6000	10.7	14	-18.6	0.0	-15.0	-27.3	-9.4	-27.4	-42.9	-27.3
SPS	6001	11.5	14	-19.1	0.0	-13.6	-27.5	-7.3	-26.6	-44.9	-28.3
WFD	1988	16.5	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WFD	5100	5.1	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WFD	5101	2.0	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WFD	1684	0.8	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WFD	1694	9.8	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
						Weighted average per BMP site					
EFD		6.1		0.8	0.0	-37.2	-27.5	-37.3	-33.3	0.0	-27.2
NFD		6.6		0.3	0.0	-8.0	-4.6	-10.0	-15.1	0.0	-1.7
NPS		5.8		-10.2	0.0	-25.1	-17.6	-25.8	-27.8	-18.9	-16.3
SFD		45.5		-0.8	-20.0	0.0	0.0	0.0	0.0	0.0	0.0
SPS		35.8		-16.7	0.0	-10.8	-26.2	-6.2	-24.7	-41.8	-27.5
WFD		34.2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.13. Summary of the BMP implementation costs for Scenario 2 (field study BMPs) for Whelp Creek Sub-watershed.[z]

BMP site	Farm size (ha)	BMP Project cost: Materials and contracts ($)	Labour ($)	Total capital cost ($)	Annual BMP cost (e.g., soil testing) ($ yr^{-1})
NFD	57	1,451	80	1,531	1,483
EFD	185	0	0	0	203
SFD	292	30	80	110	588
WFD	306	0	0	0	966
NPS	56	174	960	1,134	0
SPS	40	3,340	880	4,220	0

[z] These are BMP implementation costs incurred by the farms, as reported in the 2010 Progress Report (Olson and Kalischuk 2011).

Table 5.14. Summary of the Farm-level Economic Model annual economic results simulated for Scenario 2 (field study BMPs) relative to Scenario 1 (baseline) for Whelp Creek Sub-watershed.[z]

	Change in annual farm cost[z]				Change in net return[z]	
BMP site	Variable ($ yr^{-1})	Capital ($ yr^{-1})	Total costs ($ yr^{-1})	Total cost ($ ha^{-1} yr^{-1})	Total net return ($ yr^{-1})	Total net return ($ $ha^{-1}yr^{-1}$)
NFD	1,155	103	1,258	22.20	-2,032	-35.86
EFD	-410	0	-410	-2.22	-2,051	-11.12
SFD	-149	1,566	1,417	4.86	-4,991	-17.11
WFD	415	68	483	8.61	-483	-8.61
NPS	1,561	-449	1,112	3.63	-1,386	-4.53
SPS	42	314	356	8.80	-356	-8.80

[z] Negative numbers indicate a decrease compared to the baseline value; positive numbers indicate an increase in value.

Table 5.15. Annual average environmental and economic results based on 30-yr simulation for the outlet of the WHC Sub-watershed for different scenarios.

	Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP	Net return
	Predicted values								
Scenario[z]	(m^3 s^{-1})	(Mg yr^{-1})	--------------------------- (kg yr^{-1}) ---------------------------						(\$1,000 yr^{-1})
Scenario 1	0.024	9.9	645	243	208	439	853	683	522
Scenario 2	0.024	9.8	627	222	201	416	828	638	511
Scenario 3	0.024	10.0	570	193	209	388	779	581	504
Scenario 4	0.024	10.0	520	186	205	390	725	576	320
Scenario 5	0.013	5.4	288	106	118	195	405	301	315
	Differences[y]								
	--- (%) ---								(\$ ha^{-1} yr^{-1})
Scenario 2	-0.1	-0.9	-2.9	-8.9	-3.3	-5.4	-3.0	-6.6	-4.14
Scenario 3	0.7	0.4	-11.6	-20.7	0.4	-11.7	-8.7	-14.9	-6.74
Scenario 4	0.5	0.5	-19.4	-23.6	-1.5	-11.2	-15.0	-15.7	-74.24
Scenario 5	-47.4	-45.4	-55.4	-56.4	-43.4	-55.6	-52.5	-55.9	-75.92

[z] Scenario 1 = baseline; Scenario 2 = field study BMPs; Scenario 3 = AOPA management practices; Scenarios 4 and 5 = alternative scenarios.
[y] Differences for Scenarios 2 to 5 are expressed relative to Scenario 1 (baseline). Negative values indicate a decrease compared to the baseline.

5.4.3.2 Scenario 3 (AOPA) Simulation

The manure N application (kg yr^{-1}) in Scenario 3 was reduced by about 4% compared to Scenario 1 (baseline) (Table 5.16; Appendix 7), largely reflected in a reduction in land area receiving manure. Scenario 3 resulted in small increases (< 1%) in flow and TSS and NO_3-N losses; whereas, ON, OP, PO_4-P, OP, and TP losses decreased from 8.7 to 20.7% (Table 5.15). The model predicted that the application of AOPA setbacks would result in a greater improvement to water quality in the WHC Sub-watershed compared to the IFC Watershed (Tables 5.9 and 5.15). This difference may reflect the larger proportion of manured annual cropped land in WHC compared to IFC.

As with IFC, the soil NO_3-N levels in WHC (Figure 5.6) in Scenario 3 were less than the NO_3-N limit for this watershed (black, medium to fine textured soil, rain-fed) of 225 kg ha^{-1} NO_3-N (Table 5.3). The maximum soil NO_3-N value predicted was less than 140 kg ha^{-1}, which was for Subarea 160 in the first year of simulation. Therefore, manure application was not restricted due to NO_3-N limit exceedance.

For Scenario 1, about 50% of the land base in WHC was simulated with manure application (Table 5.16). The area used for setbacks in Scenario 3 was 91 ha, and this resulted in a decrease the total area simulated with manure application to 48%. This represents a 4% decrease of total manure applied land from Scenario 1 to Scenario 3.

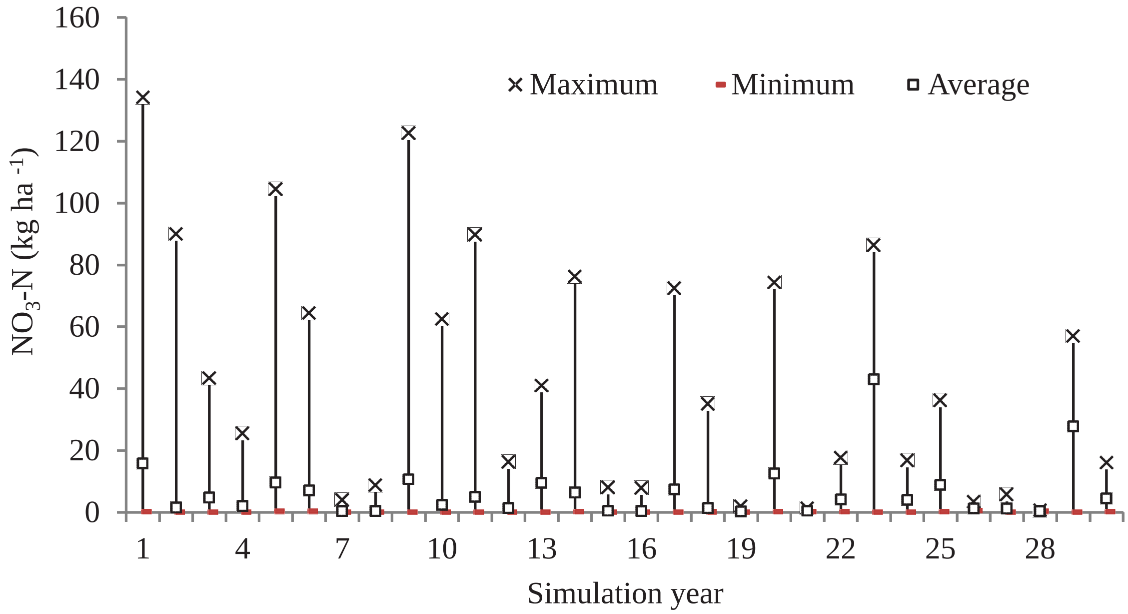


Figure 5.6. Trends in soil nitrate nitrogen (NO_3-N) levels among subareas for a 30-yr period in the WHC Sub-watershed.

Scenario 3 is projected to entail an average cost of nearly \$7 ha^{-1} annually in WHC at the watershed level (Table 5.15). Economic impacts for individual farms for Scenarios 3 to 5 are reported in Appendix 5, which shows the range of costs from one farm to another for each scenario. Total farm-level economic impacts of Scenario 3 ranged from zero up to about \$34 ha^{-1} yr^{-1} reduction in farm profits. Most of the economic impacts are due to yield reductions in the setback areas as well as slight increases in manure hauling costs since the setbacks take up land that would have received manure.

Table 5.16. Manure nitrogen and phosphorus application and BMPs implemented under different scenarios for the WHC Sub-watershed.

	Manure application			Land base of BMPs			
	Manure land base[y]	Manure N	Manure P	Setback	Grass waterway	Buffer strips	Wetlands
Scenarios[z]	(ha)	----- (kg yr^{-1}) -----		------------------------ (ha) ------------------------			
Scenario 1	2,285	157,854	57,537	0	0	0	0
Scenario 2	2,280	158,013	57,582	na[x]	0	0	0
Scenario 3	2,194	152,383	55,633	91	0	0	0
Scenario 4	2,194	130,443	32,807	91	0	0	0
Scenario 5	2,142	127,562	32,045	90	64	43	24

[z] Scenario 1 = baseline; Scenario 2 = field study BMPs; Scenario 3 = AOPA management practices; Scenario 4 = P based manure application; and Scenario 5 = P-based application, wetland restoration, reduced tillage, and buffer strips.

[y] Refers only to area receiving manure. Total land base for WHC is 4501 ha. Manure in excess of amounts that can be assimilated on land in originating farms was assumed to be hauled out of the watershed rather than being applied on neighbouring land areas within the watershed.

[x] Not available.

5.4.3.3 Scenario 4 (P-limit) Simulation

In Scenario 4, the land base for manure application occurred within the watershed was reduced by 43% compared to Scenario 1 (baseline) (Table 5.16; Appendix 7). This reduction occurred because in Scenario 4, manure was simulated to be applied based on agronomic P requirements and the model simulated that manure was hauled outside the watershed boundaries as soon as soils reached agronomic P levels. The simulated results showed further decreases in most parameters including NO_3-N (Table 5.15). As with Scenario 3, the largest reduction occurred for ON and OP losses. Similar to the results for IFC, the switch to P-based application of manure only predicted a small improvement in water quality compared to the current AOPA regulations (Scenario 3). This is probably not unexpected, because manure was applied based on crop removal of P in this simulation. This approach would prevent any further accumulation of P in soil; however, it would not reduce STP for those soils with excess P from previous manure application. In fall of 2010, the average STP measured in the field study sites ranged from 16 to 94 mg kg^{-1} in the top 15-cm soil layer, and this is likely typical for the whole watershed. Though some soils were above the agronomic threshold of 60 mg kg^{-1}, most soils, if not all, in the watershed do not have excessive concentrations of STP.

Scenario 4 resulted in an average reduction in net return of \$74.24 ha^{-1} yr^{-1} relative to the baseline for the watershed as a whole (Table 5.15). Individual representative farm results ranged from a reduction of about \$390 ha^{-1} to an increase of about \$13 ha^{-1} (Appendix 5). This reduction is largely attributable to increased manure hauling and spreading costs due to the P-based manure application restriction. Similar to IFC, manure was assumed to be hauled 8 km from the originating farm to a site outside the watershed. On the receiving field, the manure was applied using the same P-based application restriction that was imposed on the originating farm.

5.4.3.4 Scenario 5 (Riparian) Simulation

Scenario 5 included Scenario 4 with the addition of cattle restrictions to water bodies and implementation of buffer strips, grass waterways, wetland restoration, and reduced tillage operations. The results suggest that these additional BMPs may have a major improvement on water quality compared to the other scenarios.

Scenario 5 resulted in an average reduction in net returns of just under \$76 ha^{-1} yr^{-1} relative to the baseline for the watershed as a whole (Table 5.15). This was only slightly greater in magnitude than the farm-level economic impact of Scenario 4. Individual representative farm results ranged from a reduction of about \$400 ha^{-1} to an increase of about \$6 ha^{-1} (Appendix 5). The additional cost of Scenario 6 relative to Scenario 4 was due primarily to the value of foregone crop production on land placed in buffer strips and wetlands. In IFC Watershed and WHC Sub-watershed, the final scenario (Scenario 5) entailed the largest negative economic effect among the scenarios.

5.4.3.5 Cost Effectiveness of BMP Scenarios

All four alternative BMP scenarios in WHC resulted in reduced farm profits. Farm profit was reduced by less than \$10 ha^{-1} yr^{-1} for Scenarios 2 and 3 and less than \$80 ha^{-1} yr^{-1} for Scenarios 4 and 5 (Figure 5.7). Scenarios 2, 3, and 4 had little effect on TSS and flow (Figure 5.7a, b); whereas, these scenarios resulted in some reductions (3 to 16%) in TN and TP (Figure 5.7c, d). Even though Scenario 4 simulation predicted greater reductions in TN and TP compared to Scenarios 2 and 3, the reduced farm profit was 14 to 26 times more for Scenario 4. Scenario 5 simulation predicted a similar reduction in farm profit as Scenario 4; however, reductions in flow, TSS, TN, and TP were much larger than the other three scenarios. The additional BMPs in Scenario 5 (buffer strips, grass waterways, wetland restoration, and reduced tillage in the fall), only decreased farm profit marginally compared to Scenario 4, making Scenario 5 more cost effective than Scenario 4 in terms of cost and environmental improvement. While the structural practices in Scenario 5 took land out of production, the loss in revenue was mostly offset by reductions in costs of field operations.

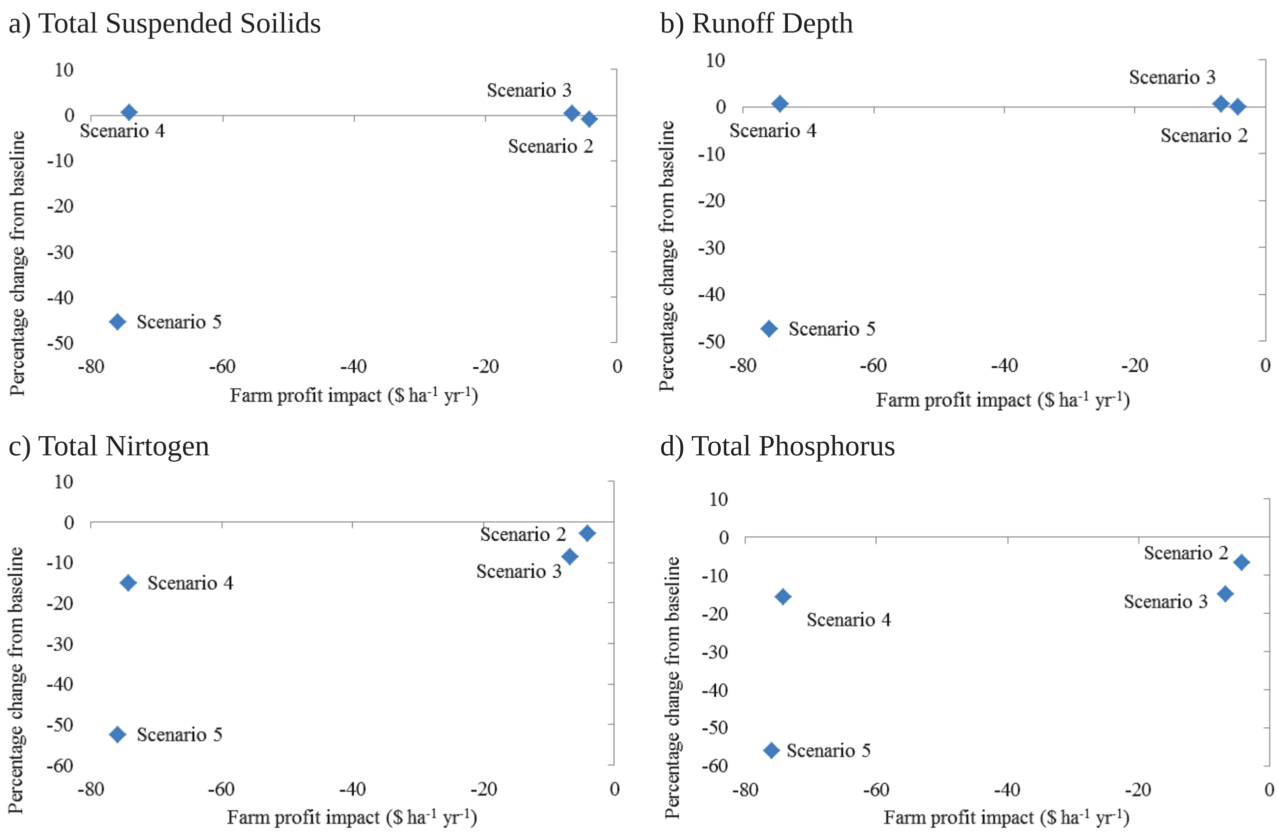


Figure 5.7. Impacts of scenarios on farm profits and (a) total suspended solids losses, (b) runoff depth, (c) total nitrogen losses, and (d) total phosphorus losses for Whelp Creek Sub-watershed.

Cost-effectiveness of each scenario for improvements in the environmental indicators of interest is summarized in Table 5.17. If TP is used as the indicator of interest, Scenario 3 (AOPA) is the most cost-effective, although Scenarios 2 is similar. On the other hand, for flow reduction, Scenario 2 is the most cost-effective. The most cost-effective scenario may not be the scenario of choice if it does not result in the level of environmental improvement desired. In that case, a combination of BMPs from different scenarios may be required to achieve the environmental objective at least cost. For example, it was identified that the large reduction in farm profit for Scenario 4 was caused by increased manure hauling for P-based application. If this component was removed from the scenario, we would expect environmental improvement with a reduced farm profit similar to Scenarios 2 and 3 or slightly greater. This approach is particularly helpful when cost-effectiveness measures are available at the sub-basin level so that alternative scenarios or BMPs can be targeted to locations where they are most cost effective rather than applying a single practice uniformly throughout an entire watershed.

5.4.4 Alternative Scenarios for the Lower Little Bow River Field

Scenario 2 (field study) included manure application based on STP concentrations, irrigation management, and a grassed waterway. Hence, Scenario 2 components were somewhat similar to Scenarios 4 and 5, although Scenario 4 assumed manure application based on agronomic P requirements. The irrigation management modelling in Scenarios 2 and 5 would be slightly different; Scenario 2 would have greater variability due to the weather variability and management logistics.

The Scenario 2 simulation resulted in a moderate to large reduction in the environmental indicators compared to the baseline. The lowest reduction was for flow, followed by TSS (Table 5.18). Total TN was reduced by 85% and TP was reduced by 56%, and most of these predicted reductions were in soluble forms (NO_3-N and PO_4-P).

Table 5.17. Cost effectiveness of alternative scenarios for the Whelp Creek Sub-watershed.[z]

	Flow	TSS	Organic N	Organic P	NO_3-N	PO_4-P	Total N	Total P
Scenario[y]	($ m^{-3})	($ Mg^{-1})	-------------------------------		($ kg^{-1})	-------------------------------		
Scenario 2	30.00	217,022	1,037	883	2,774	809	755	422
Scenario 3	-6.03	-746,966	414	615	-38,741	601	419	304
Scenario 4	-83.29	-7,132,583	2,731	5,939	110,806	6,906	2,665	3,193
Scenario 5	0.97	77,354	976	2,539	3,865	1,429	779	914

[z] Cost-effectiveness ratios are computed as change in net farm returns divided by change in relevant environmental indicator. Thus when the change in the environmental indicator is very small, the cost -effectiveness ratios would be extremely large, potentially approaching infinity when there is negligible change in the environmental indicator.
[y] Scenario 2 = field study BMPs; Scenario 3 = AOPA management practices; Scenarios 4 and 5 = alternative scenarios.

Table 5.18. Annual average environmental and economic results based on 35-yr simulation for the outlet of the Lower Little Bow River Field under different scenario model simulations.

	Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP	Net returns
					Predicted values				
Scenario[z]	x10^{-3} (m^3 s^{-1})	(Mg yr^{-1})	(kg yr^{-1})						(\$1,000 yr^{-1})
Scenario 1	0.584	1.1	2.2	1.2	101.3	33.4	103.6	34.7	$1,377
Scenario 2	0.536	0.9	1.9	0.8	13.2	14.6	15.1	15.4	$1,347
Scenario 3	0.585	1.1	2.2	1.1	95.7	31.4	97.9	32.5	$1,375
Scenario 4	0.583	1.0	2.2	0.8	72.0	14.8	74.1	15.6	$1,347
Scenario 5	0.458	0.9	1.2	0.4	64.0	14.7	65.2	15.1	$1,344
					Differences[y]				
	(%)								(\$ ha^{-1} yr^{-1})
Scenario 2	-8.1	-11	-16	-38	-87	-56	-85	-56	-44.57
Scenario 3	0.2	0	-3	-9	-6	-6	-5	-6	-7.94
Scenario 4	-7.1	-7	-4	-33	-30	-56	-28	-55	-43.98
Scenario 5	-21.6	-13	-48	-65	-37	-56	-37	-56	-47.56

[z] Scenario 1 = baseline; Scenario 2 = field study BMPs; Scenario 3 = AOPA management practices; Scenarios 4 and 5 = alternative scenarios.
[y] Differences for Scenarios 2 to 5 are expressed relative to Scenario 1 (baseline).

Because of the high concentration of STP (> 200 mg kg^{-1}) at the LLB site, the cessation of manure application was a major part of Scenario 2 and the actual BMP in the field study. It is expected, with time through crop removal, STP will decrease and reduce the amount of P loss from the field. A reduction to near or even below the agronomic threshold of 60 mg kg^{-1} would be ideal. The model simulated the change in STP during the 35-yr period for the six subareas in LLB. The model predicted an immediate reduction in STP, and after the first 3 yr, STP concentration was reduced nearly in half (Figure 5.8). In stark contrast, the actual field study showed no decrease in STP after 3 yr of no manure application. It is likely that in the field, the large build-up of organic P from manure application was able to buffer changes in STP concentration due to crop removal in the short term. Therefore, the model may have overestimated the rate of STP decline and a longer period may be required. Indraratne et al. (2009) predicted it would take 75 to 99 years for STP in excess of 300 mg kg^{-1} (Olsen extraction method) in manured soil to recover within 5% of original concentrations under southern Alberta conditions.

The model predicted that STP concentration declined from Year 1 through Year 33 at which time STP reached 60 mg kg^{-1} for Subarea 101, 201, and 203 (Figure 5.8). As a result, manure application was resumed in the simulation in Year 34, and this caused a spike in STP concentrations to more than 100 mg kg^{-1} in these subareas, resulting in no manure application for the Year 35. In the other subareas (104, 105, and 202), it took two more years until Year 35 to reduce the STP to less than the 60 mg kg^{-1} threshold.

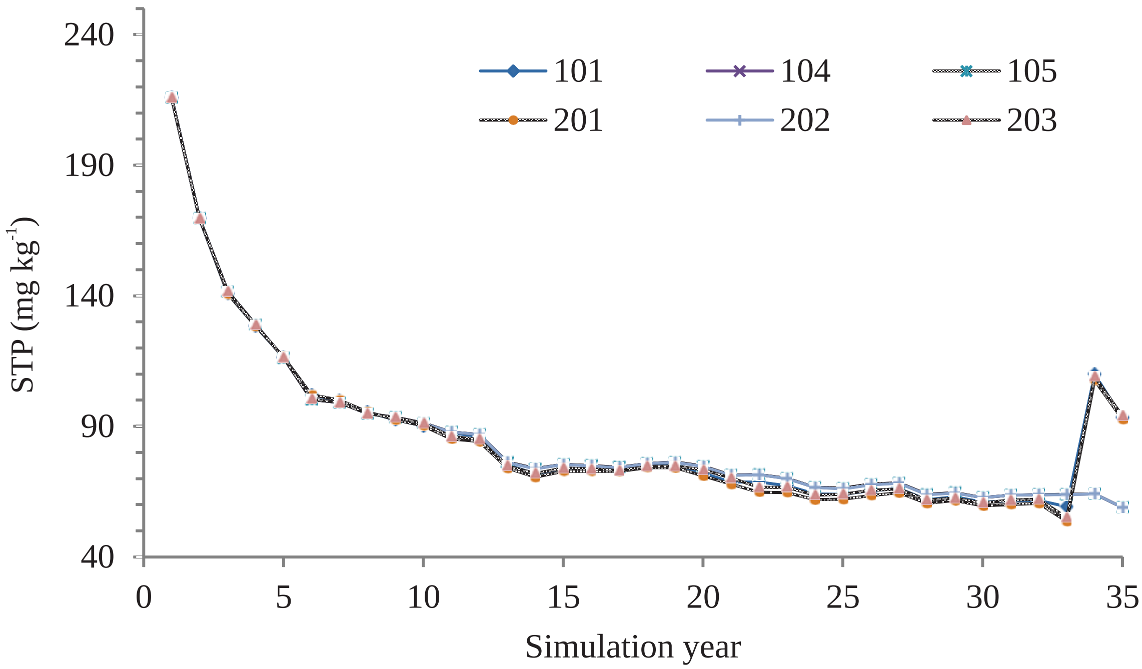


Figure 5.8. Predicted changes in soil-test phosphorus (STP) concentration by subarea at the Lower Little Bow River Field for a 35-yr period.

The model predicted much less reductions for Scenario 3 (AOPA). The largest reduction was for OP at 9% and TSS did not change compared to the baseline (Table 5.18). Predicted soil-test NO_3-N concentrations were highest for Subarea 202, with a range from about 0 to 180 kg ha^{-1} (Figure 5.9). Soil at the LLB site had more than 45% sand content and the water table may be less than 4 m below the soil surface, at least in the lower portions of the site. With these conditions, and under irrigation, the NO_3-N limit for this site is 180 kg ha^{-1} (Table 5.3). In the model simulation, soil NO_3-N levels were not high enough to warrant cessation of manure applications. As a result, the amount of reductions in nutrient losses was much lower compared to the Scenario 2, which had no manure application. The small reductions predicted for Scenario 3 may have been the result of manure setbacks from the field drainage channel for all applicable fields and incorporation of manure; whereas, the baseline simulation included setbacks only on some fields. Actual field measurements showed that average soil-test NO_3-N was about 272 kg ha^{-1} in fall 2010. Therefore, in some years, the AOPA NO_3-N limit was likely exceeded and manure should not have been applied. However, in the model simulations, the soil-test NO_3-N levels never exceeded the predetermined AOPA threshold. Consequently, the baseline manure application schedule was maintained for AOPA, except that no nutrients were applied on the setbacks simulated for each field receiving manure and manure was incorporated within 48 h of application.

There was essentially no change in flow for Scenario 3 (Table 5.18), and this was because irrigation application was not limited in the critical source area as in the Scenario 2 simulation.

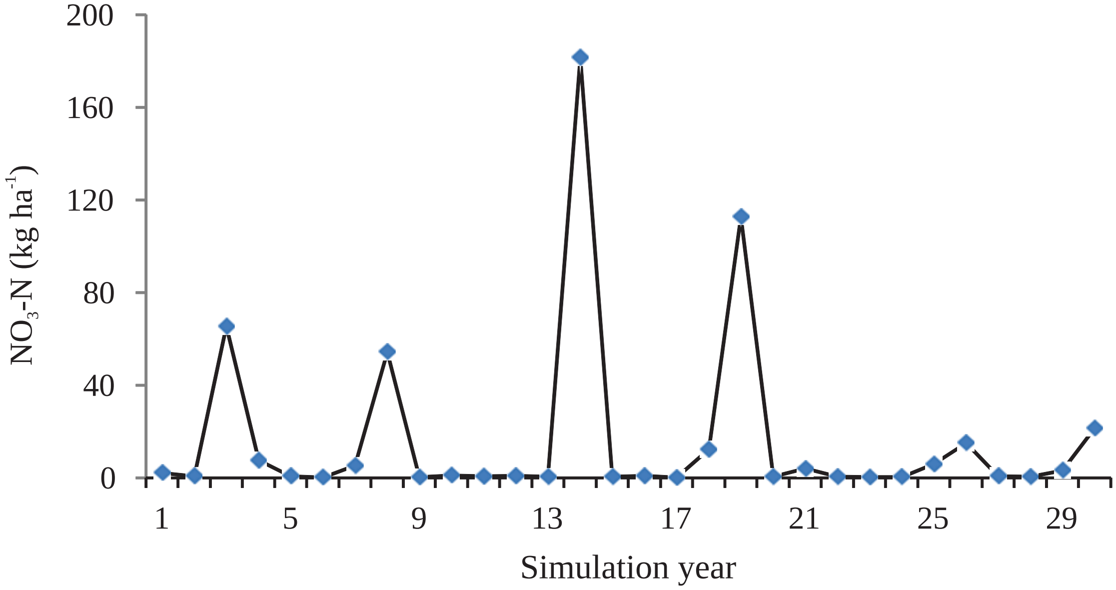


Figure 5.9. Predicted soil-text nitrate nitrogen (NO_3-N) concentration in Subarea 202 in the Lower Little Bow River Field for a 35-yr period.

Scenarios 4 and 5 had large nutrient loss reductions (Table 5.18). Similar to Scenario 2, reduced manure application rate was simulated for Scenarios 4 and 5. However, for Scenario 2 no manure was applied; whereas, for Scenarios 4 and 5 manure was applied based on crop P removal. This is likely why the reductions in NO_3-N and TN were less for these two scenarios compared to Scenario 2. Surprisingly though, the reduction in PO_4-P and TP for the Scenario 4 and 5 simulations were the same as Scenario 2, and the reduction in OP was even greater. As indicated above, the reductions in P loss in the Scenario 2 simulation could be explained by the reduction in STP with time without manure application for 35 yr. However, for Scenarios 4 and 5, manure application was simulated based on crop P, and should result in no net change in STP with time. Therefore, STP would remain high in the soil and a source for nutrient loss. Therefore, relative to Scenario 2, the model may have over predicted the reduction in nutrient loss in Scenarios 4 and 5.

The Scenario 5 simulation, which included precision irrigation management, predicted a 22% reduction in flow rate and the largest reduction in TSS loss. Scenarios 2, 4, and 5 were more expensive than Scenario 3 (Table 5.18). These three scenarios also had a greater impact on environmental indicators than Scenario 3. The main reason for the large economic and environmental impacts predicted for these three scenarios is because of reduced manure application on the field and increased hauling costs of the remaining manure. For Scenario 2, net revenue was reduced by nearly \$45 ha^{-1} yr^{-1}, or about \$34,000 yr^{-1} for the 778-ha area this farm owns. Scenarios 4 and 5 were predicted to cost from \$44 to \$48 ha^{-1} yr^{-1}.

Scatter plots showing the trade-offs between each of the environmental indicators and the associated financial impacts are shown in Figure 5.10. Depending on the indicator of interest, some scenarios are clearly superior to others. On the other hand, none of the other scenarios are shown to be superior to the others based on output from the model simulations.

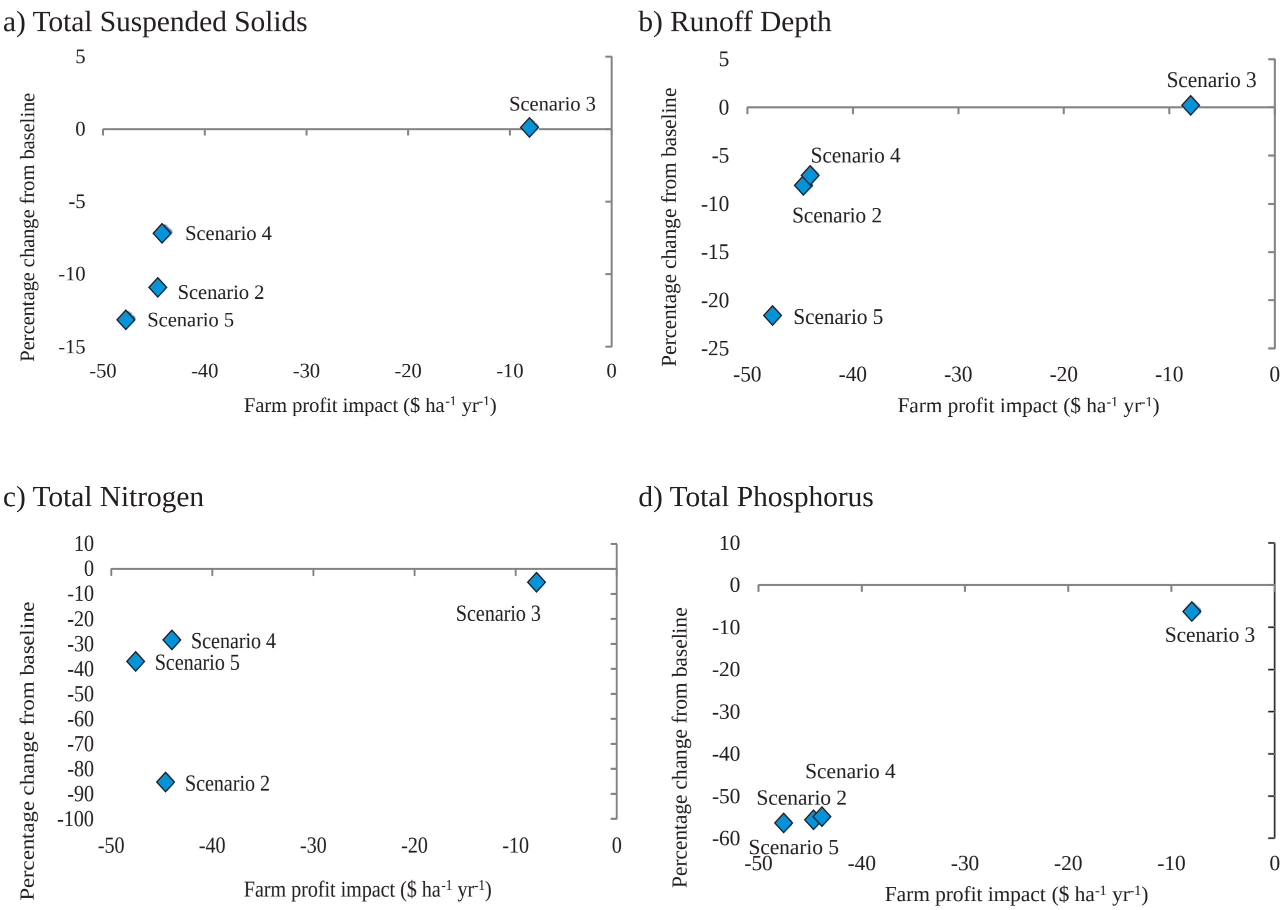


Figure 5.10. Impacts of scenarios on farm profits and (a) total suspended solids losses, (b) runoff depth, (c) total nitrogen losses, and (d) total phosphorus losses for the Lower Little Bow River Field.

Cost-effectiveness values in dollars per unit of environmental indicator reduced showed that no single scenario is superior in terms of cost-efficiency for all indicators (Table 5.19). The BMP Scenario 2 (field study BMPs) was the most cost-effective in terms of NO_3-N and TN; whereas, Scenario 5 (irrigation) was most cost-effective for OP and ON reduction. It is important to emphasize again that, as with previous watersheds, direct comparisons between the model output and actual measured impacts on the field are not always feasible due to specific circumstances in the field that are not replicable within the model. In particular, specific irrigation events or farm operations that were not adequately captured in the input data might result in economic and environmental impacts that are different from field observations.

Table 5.19. Cost-effectiveness of alternative scenarios for the Lower Little Bow River Field.								
	Flow	TSS	Organic N	Organic P	NO_3-N	PO_4-P	Total N	Total P
Scenario[z]	(\$ m^{-3})	(\$ Mg^{-1})	------------------------------		(\$ kg^{-1})	------------------------------		
Scenario 2	2.46	31,927	10,548	8,055	42	196	42	191
Scenario 3	-19.86	-522,046	9,779	6,289	117	325	116	309
Scenario 4	135.38	110,091	40,951	8,922	124	195	124	191
Scenario 5	0.99	28,444	3,632	4,952	105	210	102	201

[z] Scenario 2 = field study BMPs; Scenario 3 = AOPA management practices; Scenarios 4 and 5 = alternative scenarios.

5.5 Model Simulation Summary and Conclusions

A total of five scenarios were simulated using the CEEOT modelling system for the IFC Watershed, WHC Sub-watershed, and the LLB site. Environmental and economic impacts were derived from the CEEOT output to assist in determining the costs and effectiveness of each alternative scenario for the three study areas. Each scenario consisted of multiple scenario features or practices. As is usually the case, the impacts of the same scenario feature differed from one study area to another, based on biogeophysical properties of the areas, the distribution of scenario implementations in each area, as well as the economic profile of the farms on which those scenarios were simulated.

The scenarios simulated for the three study areas were not identical. However, the AOPA scenario (Scenario 3) had essentially the same features or requirements for all three study areas. Nonetheless, even with Scenario 3, the specific implementation of the scenario for each area was unique due to the fact that the requirements of the scenario were contingent on site specific field conditions. For instance, AOPA required manure application setbacks for fields adjacent to common water bodies, and the distribution of fields adjacent to common water bodies differed from one study area to another. Consequently, the scenario impacts cannot be compared among watersheds without due consideration to the differences in their implementation in each area.

Relative to the baseline scenario, which was defined as the status quo, the Scenario 2 (field study BMPs) was found to be effective at the field scale for each watershed. However, Scenario 2 had minor impact at the outlet of the IFC and WHC watersheds due to the fact that the proportion of the area covered by the BMPs was small. On the other hand, Scenario 2 for the LLB site had a significant impact at the outlet of that study area because the entire study area was the field site on which the BMP was implemented.

Scenario 3 (AOPA) also had varied impacts for the three areas relative to the baseline scenario. In general, AOPA was more effective for sub-basins that entailed significant areas in setbacks than in areas where the requirements of AOPA did not apply as much.

Scenarios 4 and 5 imposed progressively greater practice requirements. In IFC, cow-calf and riparian management practices were first imposed, followed by manure application restrictions based on crop P uptake rates. Conversely, the WHC analysis first imposed manure application P restrictions, and then riparian practices as well as reduced tillage. Scenarios 4 and 5 for the LLB site were generally similar to those of the WHC Sub-watershed, except that irrigation management was the additional requirement in Scenario 5 for the LLB site. Results from model simulations showed that while the riparian practices were more effective at reducing sediment and organic nutrient losses, the manure application rate restrictions were generally associated with a reduction in farm profits.

Cost-effectiveness ratios and trade-off assessment showed that some scenarios were superior to others. However, in general, optimal implementation of water quality improvement scenarios requires a combination of flexible scenario options starting with targeting the most cost effective scenarios to sites where the greatest benefit can be achieved, and progressively moving to less cost-effective options until the watershed nutrient and sediment reduction goals have been attained.

6 APPLICATION OF CEEOT TO OTHER ALBERTA WATERSHEDS

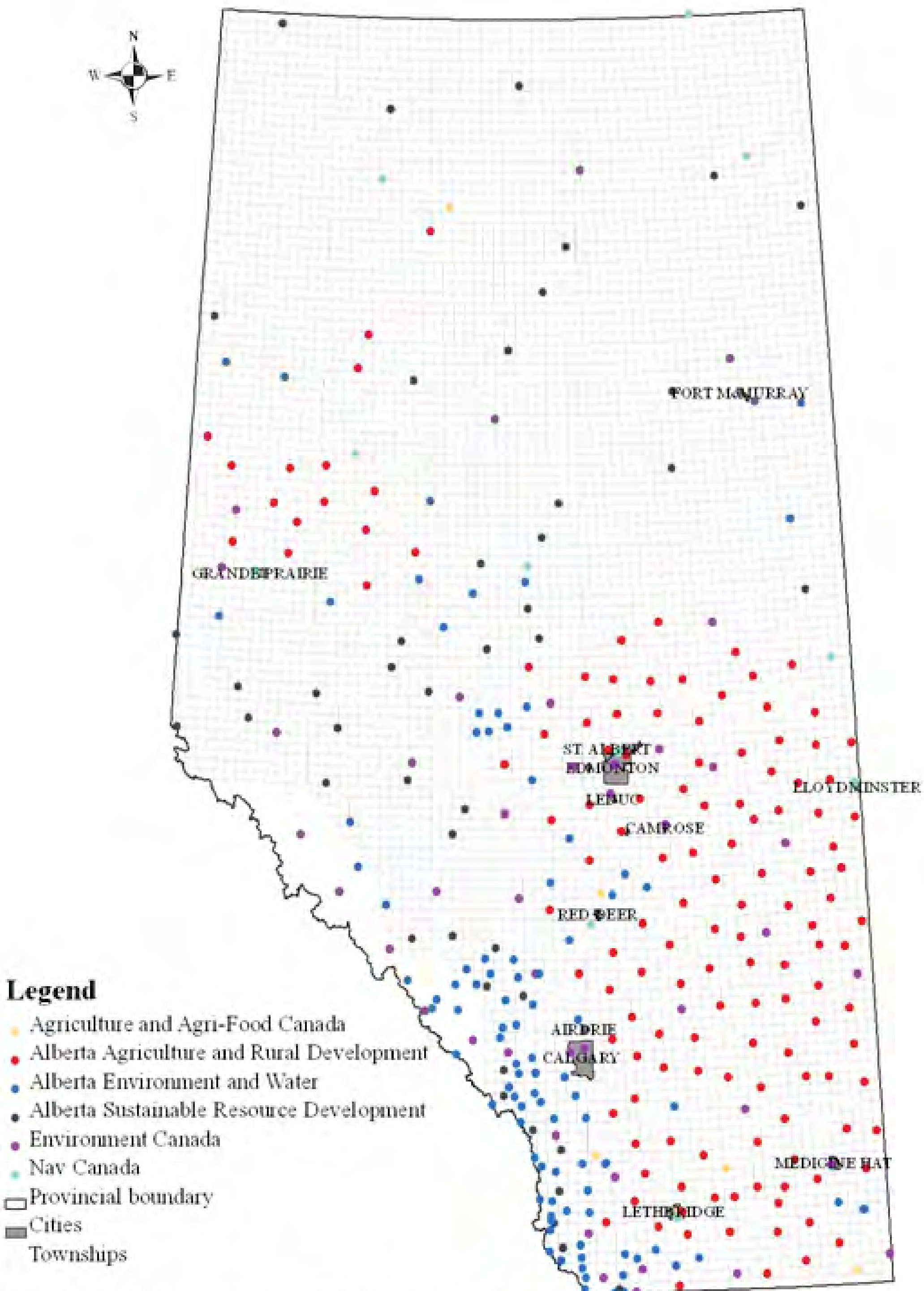
In the current study, detailed data were collected from two large agricultural watersheds (IFC and WHC) and two field-scale sites (LLB and BDF), including land management, land cover, soil data, landowner survey data, water quality data, and weather data. These data were used to calibrate the CEEOT model (Section 4), which was then used to simulate five BMP scenarios for each of the IFC, WHC, and LLB study areas (Section 5). One of the objectives of the modelling component for this study was to have a functional model that could be applied to other agricultural watersheds in Alberta. However, it is not practical or affordable to obtain the same level of detailed data for other provincial watersheds as was collected for the watersheds in this study. Nevertheless, the application of the CEEOT model at a coarser scale to other watersheds throughout the province will be beneficial in terms of BMP program assessment and development of policy options. This section will describe the requirements needed to use the CEEOT model for other watersheds, as well as provide some limitations that need to be considered.

6.1 Inventory of Available Datasets for Modelling Alberta Watersheds

Based on an inventory of the existing Alberta databases, the majority of the data are readily available at different scales/formats for use in CEEOT modelling of agricultural watersheds in Alberta. The following is a short description of existing databases. Appendices 8 and 9 provide internet or/and server links to database sources and definition of the data variables.

Climate data. Alberta likely has the most extensive network of meteorological stations in Canada (Figure 6.1). These stations measure temperature, precipitation, humidity, and wind speed, and potential evapotranspiration is determined. The network of solar radiation measurements is sparse in the province; however, the amount of data are likely suitable for CEEOT modelling. Historical (1901 to 2010) interpolated climate data (precipitation, temperature, wind, relative humidity, and solar radiation) are also available for 6900 townships in the agricultural zone of Alberta.

Surface water quality. Alberta Environment and Sustainable Resource Development (ESRD) has long-term water quality sampling stations at various locations along the primary rivers in Alberta (Figure 6.2). These long-term sites generally have data for the past 15 to 30 yr. Water samples are analyzed for conductivity, turbidity, total dissolved solids, filterable and non-filterable residue (suspended solids), dissolved oxygen , TP, TDP, TN, total Kjeldahl nitrogen (TKN), NH_3-N, NO_3-N, NO_2-N, pH, temperature, fecal coliforms, *Escherichia coli*, chlorophyll, pesticides, additional ions, and metals.



Note: Alberta Environment and Water and Alberta Sustainable Resource Development are now within one department (Alberta Environment and Sustainable Resource Development)

Figure 6.1. Network of meteorological stations with overlaid cities and townships polygons in Alberta (AgroClimatic Information Service 2009).

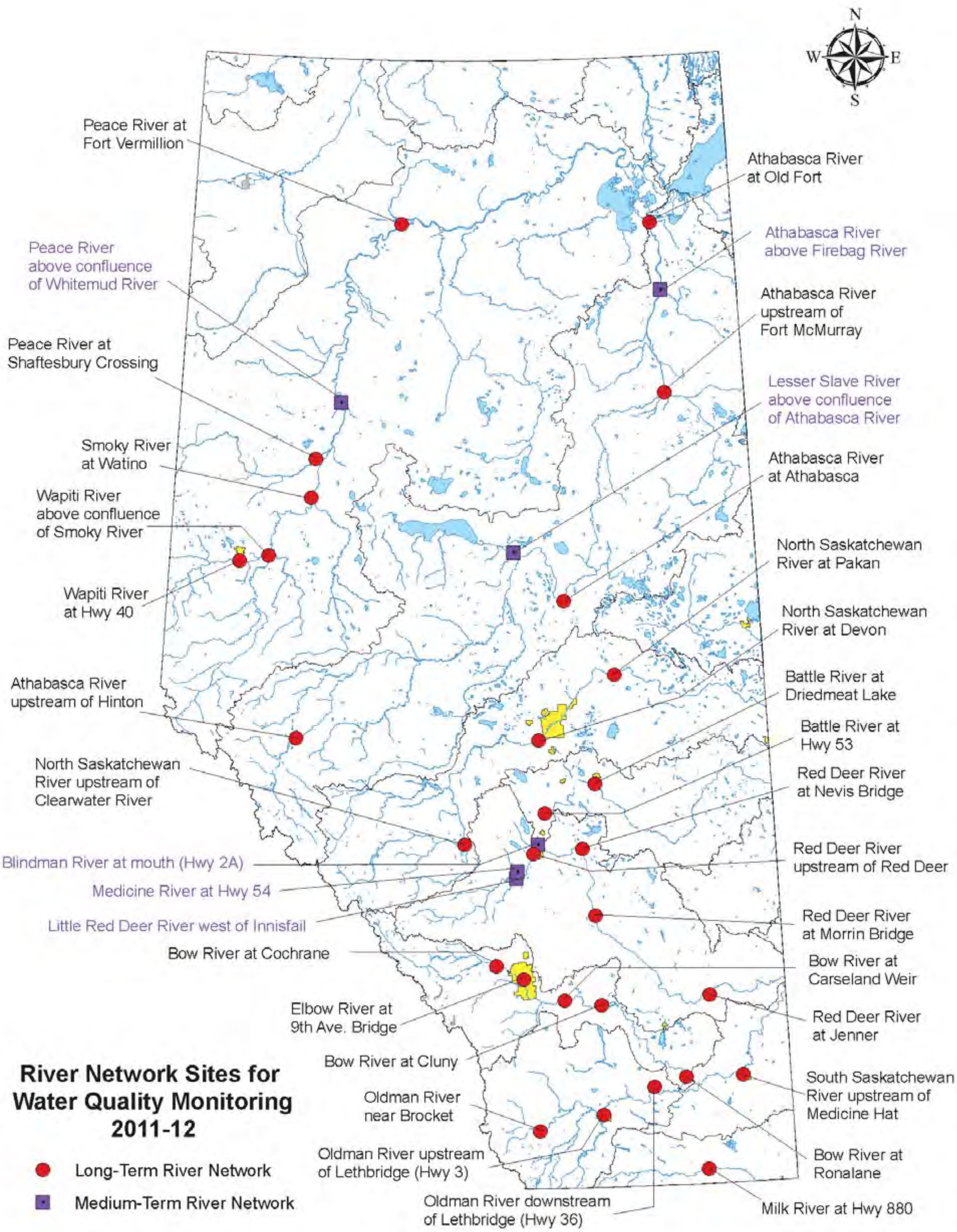


Figure 6.2. Locations of Alberta Environment and Sustainable Resource Development river water quality monitoring sites in Alberta (Alberta Environment Information Centre 2012).

Water Survey of Canada (WSC) also monitors stream discharge at 455 gauging stations and sediment concentration and losses at 124 gauging stations in Alberta. The monitoring period varies among stations; however, large amounts of data are available for at least the past 30 yr.

Water quality data were collected through the Alberta Environmentally Sustainable Agriculture (AESA) Program in 23 small agricultural watersheds (Figure 6.3) from 1997 to 2006 (Lorenz et al. 2008). Water quality parameters measured were TP, TDP, TKN, NO_3-N, NO_2-N, NH_3-N, non-filterable residue (suspended solids), pH, temperature, conductivity, fecal coliforms, *Escherichia coli*, and a variety of pesticides. Total particulate phosphorus (TPP) was calculated as TPP = TP – TDP and TN was calculated as TN = TKN + NO_3-N + NO_2-N.

It is important to recognize that the availability of the existing water quality and quantity data vary among ESRD and WSC monitoring stations. Most of the WSC stations include flow data; whereas, the sediment data are available at fewer stations. Also, not all ERSD stations have flow and water quality data. Some stations may have flow data but no water quality data, and vice versa.

Lake specifications and water quality. Bathymetry for large Alberta lakes is available from the Alberta Geological Society. Lake volumes can be estimated from the bathymetry data. Lake levels and water quality data are available from ESRD.

Reservoir specifications. Reservoir volume and surface area at full supply level, construction date, location, and diagrams of the larger reservoirs are available from Water Management Operations at ESRD.

Surface water and groundwater usage. Allocation amounts of creek, river, or groundwater for each section of land are available from ESRD. Water usage can be estimated from the amount allotted to municipalities and industries. Actual water use relative to allocation amounts has been approximated by ESRD for each type of water user.

Wastewater treatment plants. Data such as discharge rates and water quality analyses are only available from individual municipalities. To find a wastewater treatment facility for a particular community or county, a search tool is provided by ESRD.

Elevation data. The 30-m grid of elevation postings in the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM are at a suitable resolution and quality for application in large watersheds. Consideration will need to be given on how the implementation of BMPs can be applied at this resolution, as well as at coarser or finer scales.

Land use and land cover. The majority of water quality data in Alberta is from 1995 to 2006. Therefore, the satellite image data from about 2000 developed by Agriculture and Agri-Food Canada (AAFC) appears to be the most suitable for future CEEOT applications. The land cover classification was designed to distinguish between types of agricultural coverage and is likely the best for modelling purposes.

Soil. The Agricultural Region of Alberta Soil Inventory Database (AGRASID) is the most extensive soil dataset for Alberta, as described in Sub-section 2.1.3 of this report (Alberta Soil Information Centre 2001). Soil attributes are included for each soil type, with detailed information

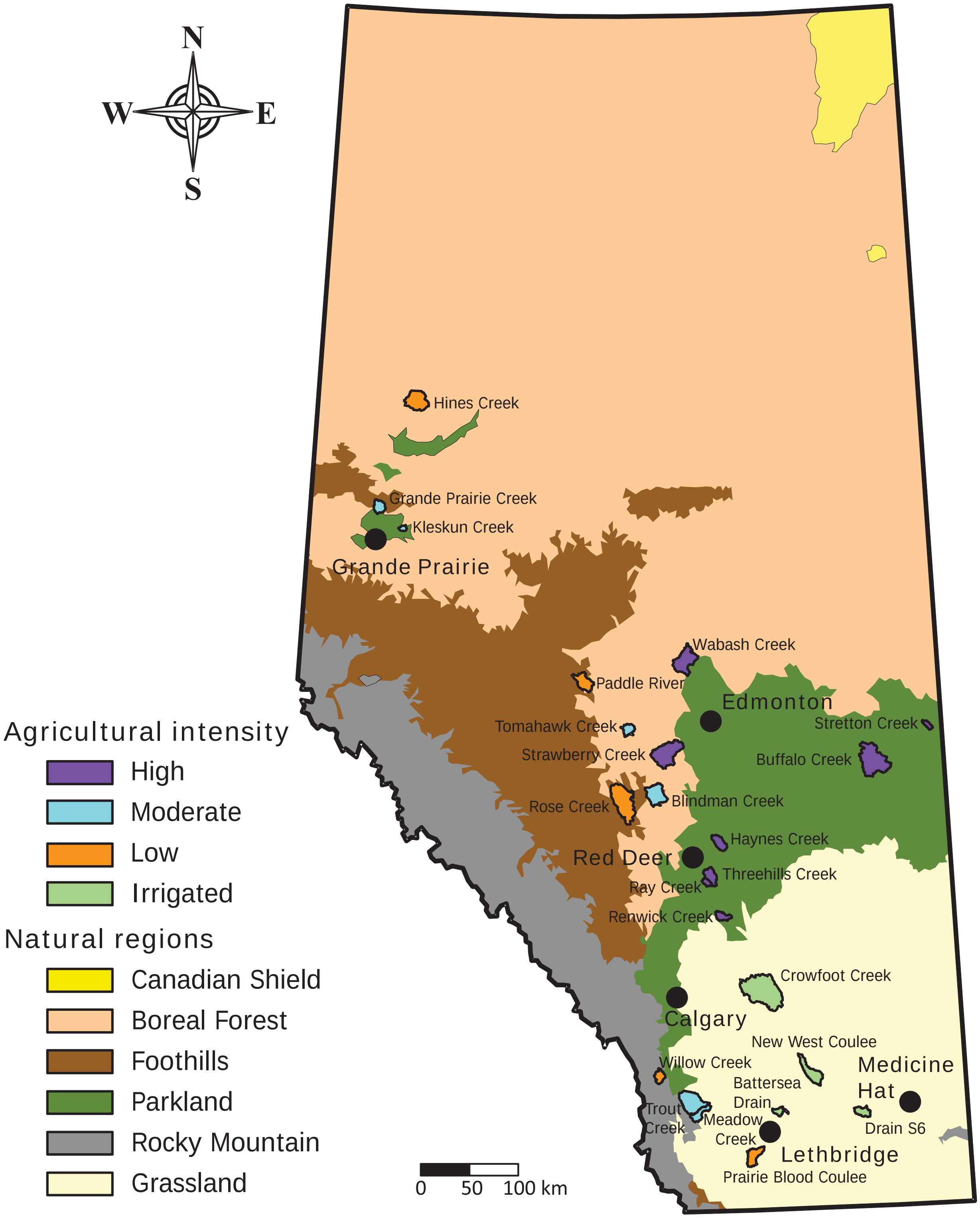


Figure 6.3. Locations of the 23 Alberta Environmental Sustainable Agriculture Program (1999 to 2006) watersheds in Alberta (Lorenz et al. 2008).

for each soil layer, such as layer depths, sand, silt, and clay fractions, organic carbon content, pH, base saturation, cation exchange capacity, saturated hydraulic conductivity, water retention, bulk density, and electrical conductivity.

Groundwater. Regional groundwater assessments have been completed for most agricultural counties in Alberta (Figure 6.4) by Hydrogeological Consultants Ltd. and the Alberta Geological Society. The regional assessments spatially identify the aquifers within the surficial deposits and upper bedrock, describe the quantity and quality of each aquifer, and identify the hydraulic relationships between aquifers. Additional groundwater depths are available from the ESRD water well information database.

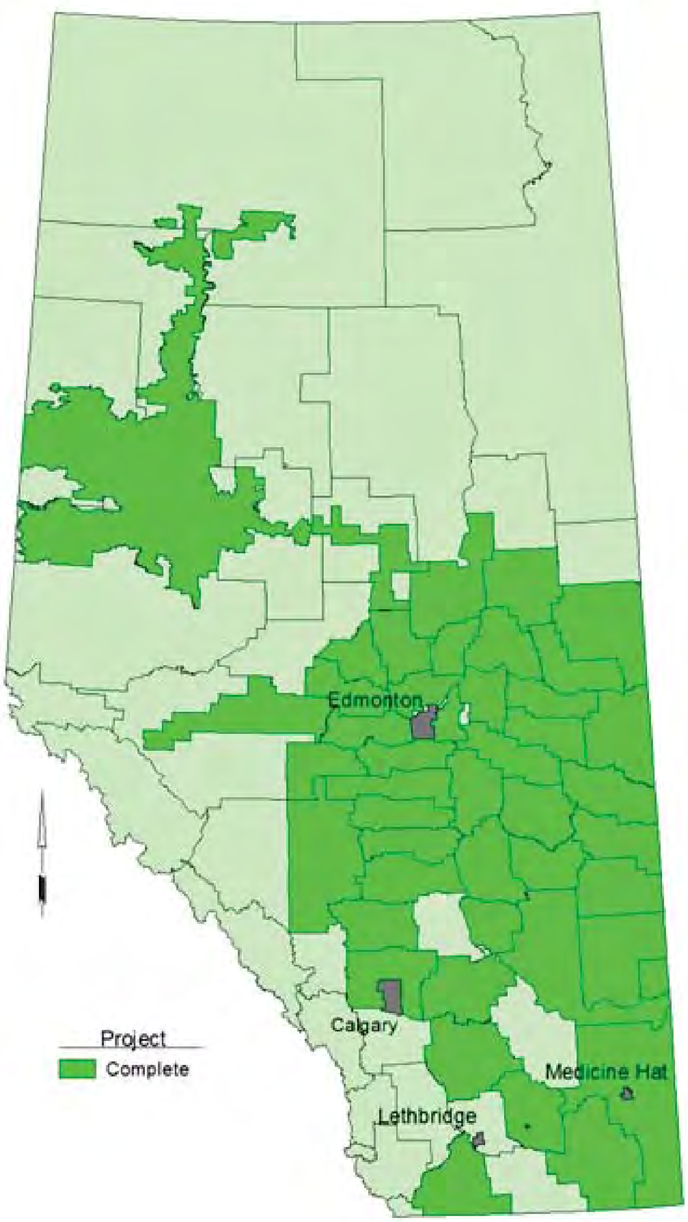


Figure 6.4. Counties in Alberta with completed groundwater assessments (Hydrogeological Consultants, Ltd. 2010).

Farm operations. Farm operations are best summarized by the Statistics Canada Census of Agriculture, which is georeferenced at a variety of scales. Available data scales include census division, PFRA (Prairie Farm Rehabilitation Administration) watersheds, soil landscapes of Canada polygon, and ecodistrict. Of these, the PFRA watersheds (Figure 6.5) are the smallest and correspond to the locations of the WSC stream gauging stations. Most of the Census of Agriculture data applicable for modelling is outlined in Appendix 9, but note that Appendix 9 does not include every variable.

Figure 6.5. Watershed boundaries of PFRA watersheds in Alberta (Godwin and Martin 1975).

Farm input prices. Crop prices are available from the Alberta Financial Services Corporation (AFSC) website. Livestock prices are available from Canfax and from ARD AgriProfit$ database. Prices for primary fertilizer and chemical inputs are available from the ARD Agricultural Input database.

Crop yields. Provincial average crop yields are available from ARD databases compiled from Statistics Canada data. Regional crop yields are available for major crops from ARD databases.

Crop and livestock farm production costs. Production cost estimates are available from the ARD AgriProfit$ database.

6.2 Macros and Extension Tools Developed for CEEOT Input Data Preparation

In order to facilitate CEEOT simulations for the three watersheds in this study, the following programming extensions were developed as external augmentations to the CEEOT model. These extensions will be embedded into the CEEOT program in order to facilitate seamless CEEOT applications in other Alberta watersheds.

6.2.1 Input File Creation

The input files used in all three CEEOT models (APEX, SWAT, and FEM) were based largely on farm survey data. A detailed farm survey was conducted at the beginning of the project, and this was followed by annual surveys of participating producers that had BMP sites installed on their properties. Survey data were received in Microsoft® Word® forms. The information for each farm was then transferred to a separate, standardized Microsoft® Excel® spreadsheet. In order to generate the APEX, SWAT, and FEM input files, a Visual Basic macro was written to transfer the farm data into SWAT and FEM input files. For land uses that need to be simulated in APEX, the SWAT files were then converted into APEX using CEEOT's built-in file conversion tools. The FEM project files ready for FEM simulation were also generated after execution of the macro using FEM's built-in file import utilities.

The Microsoft® Excel® input file generation macro can be used for any watershed assessment where similar survey data are available. For watersheds where no survey data are available, representative farms can be generated from aggregate farm data sources such as the quinquennial census or other published aggregate farm data tables. From these sources, the size of representative farms, crop rotations, and livestock herds can be established. The representative farms thus defined can be augmented with management practice information available from ARD staff or local experts in the county or watershed of interest.

6.2.2 Representative Farm Definition

Osei et al. (2003a) and Osei et al. (2008a) developed a data disaggregation and statistical clustering procedure for generating representative farms from aggregate farm data. The procedure was applied to the United States Agricultural Census to develop representative farm data for all states and counties in the United States. A similar procedure will be incorporated into the CEEOT interface and used to develop representative farm information from the county-level or watershed-scale Agricultural Census data for Alberta. With this procedure, the aggregate data are first disaggregated to recreate a distribution of farms that is very close to the actual population of farms in the watershed or county of interest. Then, simple statistical clustering procedures are used to categorize the list of farms into groups using selected farm attributes and defining one or more representative farms for each group.

6.2.3 SWAT Management File Assignment

Farm survey data collected during the field study represented only a small portion of area in each watershed. For APEX and SWAT simulations of all the other land areas in the watersheds, it was necessary that the input fields generated for the surveyed areas be applied to these other areas as well. For this purpose, a routine was developed that assigned management files to each hydrologic response unit (HRU) based on land-use distribution. A manual check of these assignments was required to ensure they were reasonable.

6.2.4 Customized Scenario Input File Generation

The CEEOT model contains a number of built-in scenario generation features. However, for this study, many detailed scenario features needed to be applied to various land areas. Thus, routines were developed to allow for the design of custom scenario features. The following are specific features that were developed for the IFC and WHC watersheds and the LLB site, and used in simulating the scenarios reported in Section 5.

Limits on nutrient applications. One of the routines developed as part of this effort allows for manure and other nutrient applications to be based on crop P or N agronomic requirements. These are calculated based on average crop yields. In the scenario simulations of the present project (Section 5), only the P agronomic restriction was used in Scenario 5 for IFC, in Scenarios 4 and 5 for WHC, and in Scenarios 2, 4, and 5 for LLB.

Timing of field operations. This feature allows for field operations to be changed to different dates as needed. The macro simply reads in all the field operations and modifies the dates of the ones in question, moving them to the new chronological sequence in the operation files as required by the scenario being simulated. This feature was used for simulating scenarios that prohibited manure applications in the fall or winter months or on frozen ground and allowed the application of manure in the spring and early summer.

Structural practices. Flexibility was introduced in scenario definitions to include requirements for setbacks, grassed waterways, wetlands, and other structural features. To enable simulation of these features, a routine was developed that modified the APEX sub-basin files for each sub-basin of each watershed. The structural feature required for the scenario being simulated was inserted in the right location within the sub-basin file and the subarea sizes and other attributes were modified accordingly.

Modification of tillage operations. The routine developed to modify timing of field operations also provided an option for elimination of tillage operations as needed. This specific feature was used for elimination of deep tillage operations in the WHC watershed, except in instances where the tillage operation in question was the only operation in a given year.

Incorporation of manure. Manure incorporation is an option in the routine developed for tillage and timing features. This routine provides two options for manure incorporation: (1) adjust the nutrient application depth for manure applications in the APEX operations file or (2) add a specific tillage operation on a specified date after manure has been applied. In the scenario simulations for IFC and WHC (Section 5), the first option was used in order to avoid unnecessary soil disturbance that might mask the results of the simulations.

Soil nutrient limit application. Due to the need to simulate soil NO_3-N limits in AOPA, a special routine was developed that iterates through APEX simulations, stopping simulation at the end of each year of the simulation horizon to determine if soil nutrient levels warranted manure applications in the following year. In this routine, the soil NO_3-N level was computed based on the concentration in the 0- to 0.6-m soil layer, as specified in AOPA (Province of Alberta 2010). The soil NO_3-N concentration (mg kg^{-1}) was multiplied by the soil bulk density to obtain the total mass per unit area, expressed in kilograms per hectare.

6.3 Procedure for BMP and Scenario Assessment

The CEEOT system has been used to evaluate a wide array of BMPs and other scenarios in a number of watersheds. The tool can also handle combinations of BMPs and scenarios that do not necessarily involve BMPs. In Osei et al. (2009), a protocol was outlined to enable CEEOT users to apply the modelling system efficiently in any watershed and the protocol could be used for any watershed within Alberta. The protocol document discusses pertinent topics such as how to define baseline and alternative scenarios, the kinds of practices or scenarios that can be simulated in CEEOT, and how to interpret model results, among others. The document provides a step-by-step guide that will enhance the application of CEEOT in watershed assessments. The reader is referred to the protocol document (Osei et al. 2009) for additional details on how to perform watershed assessments, particularly with the CEEOT system.

6.4 Limitations of CEEOT Applications in Other Alberta Watersheds

One of the primary objectives of the CEEOT application to the three study watersheds (IFC, WHC, and LLB) was to develop a framework and protocol for rapid application of the model to other watersheds in Alberta. It is anticipated that future CEEOT applications in other watersheds in the province will not entail the same level of detail of effort and data collection as was the case for the IFC, WHC, and LLB watersheds. However, while similar analyses can be accomplished with less effort, there are a number of limitations of any CEEOT application, particularly as compared to the detailed approach used for the three study watersheds. There are two main limitations: data and scope.

Data limitations. The detailed data assembled for the current study will generally not be available for other watersheds. Thus, CEEOT applications to other watersheds will be at a coarser scale. There will be limited calibrations and the analyses derived from the model simulations will be applicable in a broader sense.

Scope limitations. The CEEOT model is applicable primarily to agricultural land uses. While plans are under way to include urban land simulations within the model, this has not yet been implemented. Therefore, there will be limited applicability to watersheds that contain significant non-agricultural land uses.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Lessons Learned from CEEOT Application in Alberta

7.1.1 Field Measurement Data Lessons

BMP simulation efforts were limited because it was not feasible to adequately compare field BMP measured effects against the CEEOT BMP simulation results. The field measurement data available for BMP assessment were of relatively short duration. While the spatial distribution of water monitoring stations was fairly good, only 1 or 2 yr of measured data of post-BMP management conditions were available for the CEEOT simulations, which were run for either a 30- or 35-yr period. It would be ideal to have field measurement data of longer duration for model validation.

7.1.2 Model Calibration Lessons

The strategy for application of the SWAPP model was based on the assumption that it would be possible to calibrate the model and eventually evaluate BMP scenarios at the same time that field data were collected and analysed. This assumption was incorrect because issues arose with the existing input data or with recently collected field data. For example, the initial DEM data had 25-m grid resolution and only after attempting to calibrate at the field scale did it become evident that the 25-m resolution was not suitable. Therefore, late in 2008, more accurate DEM data (LiDAR 1-m and 5-m grid) were acquired and watershed delineation and configuration were redone. In addition, the locations of all the BMP monitoring stations were not all identified at the start of the project and new BMP sites were established late in 2008 and early 2009. Due to these changes, the initial watershed delineation was no longer valid and also needed to be redone. Furthermore, field data were not always fully analyzed and verified at the time of model calibration, and some of the field data entered into SWAPP had to be adjusted at the same time as the calibrations were conducted.

To avoid similar calibration issues at the end of 2010, no new data were added to SWAPP. Instead, the previously entered data from 2009 were verified again and calibrations were conducted one more time. The expectation was that this calibration process would improve the 2009 calibration results and the 2010 field data would be used to validate SWAPP in 2011. However, the 2009 calibration results were still not satisfactory due to poor model performance in the 2008 and 2009 drought years, so additional calibration was conducted in 2011 using 2010 field data.

This calibration approach was not very efficient because it involved three series (2009, 2010, and 2011) of data entry and calibration procedures. In general, it does not take much more time to input 3 yr of data than 1 yr of data, and likewise the time requirements for model calibration are similar using 1 yr or 3 yr of data. Based on these experiences, we suggest that any future modelling project should not be initiated until all of the field data are available and the data quality has been verified.

A significant amount of time was dedicated to improve SWAPP calibration results at the field-scale and watershed outlets. However, the final predictions of sediment and nutrient losses at this very detailed scale were not accurate enough to justify the time spent performing such refined calibrations. Based on the experience gained from the SWAPP calibrations, we suggest that for future similar projects, SWAPP should not be calibrated at such a detailed scale. Instead, we recommend calibrating it for the outlets of larger areas about the size of the WHC or IFC watersheds. The research team agreed that this approach of SWAPP calibration would be adequate for relative evaluation of the cumulative effects of BMP implementation.

A notable lesson related to the foregoing is that virtually all computer simulation models are severely limited when used to mimic very low flow conditions as was typical of the IFC and WHC field-scale stations. Consequently, when selecting watersheds it would be helpful to choose ones where significant flow volumes are expected under normal weather conditions. When flow volumes are very low, some of the differences attributed to the BMP or scenario being evaluated may well be due to other unrelated factors such as measurement error or malfunctioning of sampling devices. In addition, very low flow volumes are often well below the predictive ability of the simulation models being used.

7.1.3 Model Performance Lessons

There were a number of issues with the performance of the SWAPP interface. These issues came to surface during different phases of the project and very often caused the SWAT or APEX model simulation to crash. Based on the frequency of these crashes, we learned that the SWAPP interface was still in a development stage and provided a challenge to new users. Some of the issues were attributable to the complexity of hydrological processes in the Canadian prairies, the size of the sub-basin areas, and the number of subareas in each sub-basin. For example, it was particularly challenging for SWAPP to simulate snowmelt events, summer drought conditions, and the sequence of surface flow among subareas where ponds and wetlands were present. In addition, the APEX manual was last updated in June 2008, and some input and outputs from the most recent version of the APEX model did not correspond to references provided in the manual. During the 4 yr of the modelling project, the following six improvements were implemented, either to the SWAPP interface or to APEX to improve model performance:

1. APEX grossly overestimated the effect of ponds because it did not account for return flow amounts when ponds were present in the subarea. This problem was solved by revising the pond calculation subroutine in APEX.

2. APEX crashed due to an error in the input to the sequence routing. This issue was resolved in the “saf” files, where many urban subareas were not included in the APEX inputs even though they were used in routing.
3. APEX crashed due to a limited number (1000) of subareas allowed to be simulated in any sub-basin. This issue was resolved by increasing the limit to 9000 subareas.
4. APEX crashed due to a limited number (15) of irrigation operations per year that APEX was able to accept. This problem was solved by increasing the limit from 15 to 20 operations.
5. APEX was not predicting the timing of the snowmelt events correctly at the sub-basin scale. This problem was solved by providing the option of overwriting inputs of Parameters 22 and 80 from the PARM0604.DAT file for each sub-basin “sba” file.
6. In the last version of APEX, the PARM0604.DAT file has five more parameters that were added to help with APEX calibrations.

7.1.4 Farm Data Development Lessons

The representative farms for the BMP Project were based on farm surveys in the study watersheds. As a result, they varied considerably in size and character. Some of the actual farms had land outside of the study areas and this led to some issues regarding the calculation of capital costs. Future applications of CEEOT in Alberta should be based on a smaller number of representative farms developed to reflect average farm characteristics in watersheds.

The crop rotations of actual farms in the BMP Project also varied considerably. This led to extra efforts in developing the data input tables. Future applications should use more standardized crop rotations that are derived from actual historical cropping patterns as part of the process of defining statistically valid representative farms.

7.1.5 Farm Equipment and Facilities Lessons

The default machinery list may not adequately reflect current farm machinery used in Alberta. The list of equipment and purchase prices are presently being updated for future applications of CEEOT in Alberta. As well, detailed information on farm facilities was only available for Alberta dairy enterprises. Facility values for other farm enterprises should be identified for future studies.

7.1.6 Scenario Simulation Lessons

BMP scenarios were developed for the IFC and WHC watersheds and the LLB site with the objective of evaluating environmental changes and economic impacts of BMPs related to manure application, livestock management, late-fall tillage operations, irrigation efficiency, and other management practices. Each scenario included a suite of BMP practices (Sub-section 5.1.2). Due to this simulation approach, the CEEOT model was only able to evaluate the outcome of implementing the suite of BMPs established in each BMP scenario, and not the effects of individual BMPs within each scenario. In future projects, it is suggested that the effects of individual BMPs be simulated first before evaluating scenarios consisting of combinations of

BMPs. In other words, if a scenario containing multiple practices is evaluated, it is difficult to determine which practices within that scenario were responsible for the impacts observed. To gain a better understanding of the scenario impacts, it is helpful to simulate scenarios that contain only one practice or feature before combining them into another scenario that consists of multiple practices.

7.2 Recommendations for Future CEEOT Model Developments

In the BMP Project, the CEEOT model was calibrated and tested for two agricultural watersheds and one field site, and proved to be a powerful modelling tool. In spite of many positive features, we discovered that CEEOT framework had some modelling limitations.

Concentration values in the model output are required to assist in interpretation.

- Water quality is most often evaluated and interpreted with compliance to federal and provincial water quality guidelines, which are concentration based. In the current modelling study, nutrient and sediment losses in surface water were expressed as export coefficients (kg $ha^{-1}yr^{-1}$ or Mg ha^{-1} yr^{-1}) are useful to determine impacts within a closed basin and in particular, loading impacts on lakes. However, concentration data are required to determine acute water quality conditions, such as toxicity, and concerns to water users and the protection of aquatic life.

Simulation of composite scenario analysis and different manure/fertilizer application options on individual fields needs to be fully automated.

- Currently, the scenario analysis component of the CEEOT model can only model (implement) one BMP at a time. However, in the BMP Project, each scenario included a number of BMPs. In addition, there were issues dealing with nutrient application and management. The manure/fertilizer application BMP was based on crop P and N requirements; however, CEEOT does not take into account the existing annual variability of soil P and N levels based on manure or fertilizer applications. Also, the BMP manure/fertilizer P and N application rates were established after examination of actual soil N and P content. Due to these CEEOT limitations, the scenario development and the input data for the manure/fertilizer based BMPs were prepared outside the CEEOT model using Excel® macros. To address these limitations, several Excel® macros and extension programming tools were developed during the course of the BMP Project. Incorporation of these extension tools into the CEEOT framework will help to address these constraints and improve the model's functionality.

Definition of routing sequence of subareas in the APEX subarea input file needs automation.

- Generally, the AvSWAT program automatically generates the sub-basin area hydrological routing sequence for SWAT and then the user can automatically generate the subarea routing sequence for the APEX model with CEEOT. However, in the BMP Project, the IFC and WHC watersheds had a large number of subareas and the automatic preparation of subarea routing sequences for each sub-basin was not possible. Therefore, the routing schemes for

APEX for the IFC and WHC watersheds were prepared partially manually and partially with the use of Excel® macros. The process was time consuming and subject to development errors, which required more time for quality checks and verification. To address these difficulties, integration of the Excel® macros and other tools that were used in the project into the CEEOT interface would streamline the process of defining subareas and farm management files prior to simulating the scenarios.

The creation of FEM input data for composite BMP scenarios needs development.

- The CEEOT framework has the ability to automatically prepare input data files for APEX and FEM models using the SWAT files from the “txtinout” directory. However, in the BMP Project, only APEX files were prepared within the CEEOT model. The FEM input files were prepared through a large Excel® workbook with data and information widely placed on individual worksheets. The data were input into FEM initially by applying a VBA script designed to gather all of the information in a certain order. Also, FEM simulations were conducted outside the main CEEOT interface. As a recommendation to improve future applications, it would be useful to increase standardization or compactness of the input tables to improve the ease of data entry, and to simplify the degree of VBA programming required to transfer the information to FEM.

The results from FEM simulations should be available at the field-scale.

- The output files generated by FEM report costs primarily at the whole-farm level. Another useful recommendation to improve CEEOT applications would be to add output files reporting data at the field-scale, in terms of providing useful output for economic analysis, and to provide additional means of reviewing or testing the model output.

Facilities and equipment data need to be developed for all types of farm enterprises in Alberta.

- Data currently available on equipment complements and facilities on farm enterprises do not cover all relevant farm types. Only data for dairy equipment and facilities were available for the provincial watershed assessments. Future economic evaluations for various watersheds in Alberta would be improved by obtaining reliable data on equipment and facilities on typical farms in the province.

In addition to the benefits of estimating the economic and environmental implications of alternative BMP scenarios, the CEEOT model application to the IFC and WHC watersheds and the LLB site also provided a number of benefits in terms of improved and readily available tools for future applications in other watersheds in Alberta.

7.3 Conclusions, Key Findings, and Recommendations

The results of the model simulations showed that the BMP scenario performance was site and watershed specific, and confirmed several conclusions from the field study. This provides confidence that future modelling efforts may not need as detailed ground truthing as was completed during the Nutrient BMP Evaluation Project.

- Scenario 2 (field study BMPs) did not result in large water quality improvements at the watershed outlets when compared to the baseline. This reflects the few BMPs that were implemented in the watersheds relative to the land base of the watersheds. In contrast, at the edge-of-field, significant water quality improvements was predicted by the implementation of BMPs.

- Scenario 3 (AOPA) was more effective at improving water quality than the baseline and Scenario 2, but not by much. This is because the two previous scenarios were very similar to Scenario 3 with the one distinguishing feature in Scenario 3 being the manure application setbacks. The environmental and, to a lesser extent, the economic impacts of AOPA were shown to be predicated upon the distribution of manure application fields and common bodies of water, i.e., the more manure fields closer to water bodies, the greater the impacts. This was illustrated as Scenario 3 resulted in greater water quality improvements in WHC than elsewhere, because WHC had relatively greater numbers of manured fields and common water bodies. Another finding related to AOPA is that the soil NO_3-N limits were largely unbinding in effect because most soils in the two watersheds were less than the thresholds given in AOPA during the 30- or 35-yr simulation horizon.

- Scenarios 4 and 5 were generally designed to address the perceived water quality issues. In IFC, the addition of Scenario 4 with cow-calf and riparian BMPs resulted in the largest environmental gains and it was also the most cost effective scenario. Adding an agronomic P-limit in Scenario 5 had little impact, as there were less than six fields in IFC that had received manure.

- The agronomic P-limit in Scenario 4 for WHC resulted in some improvement in comparison to the AOPA NO_3-N limit in Scenario 3. However, it was the buffer strips, grassed waterways, and wetland restoration in Scenario 5 that showed the greatest environmental improvements in WHC, albeit at a significant cost.

- Scenarios 4 (agronomic P-limit) and 5 (irrigation management) were slight variations on the approach taken in the field for Scenario 2 at the LLB site. Environmental and economic results were generally similar between the scenarios, confirming that water quality at the site is likely to be improved but there will be a significant cost to haul the manure.

Riparian and cow-calf BMPs that involved structural controls such as wetlands, off-stream watering, setbacks, buffer strips, fencing, and grass waterways resulted in significant reductions in sediment and nutrient losses.

- In WHC, the riparian BMPs resulted in about 50% reduction of TSS, TN and TP compared to the baseline scenario. In IFC, the cow-calf and riparian BMPs resulted in about 25% reduction of TSS and about 60 to 50% reduction of TN and TP, respectively, compared to the baseline scenario. Although the percent reductions appear substantial in both watersheds, WHC generally had very low concentrations of TSS and particulate nutrients, so the reduction may not be biologically significant. In contrast, IFC TSS and particulate nutrient concentrations were relatively high, and reduction in these parameters may be environmentally beneficial.

- The economic impacts of these controls were minimal in areas where prime cropland was not involved because the opportunity cost of the land placed in these structural controls was relatively low when compared to higher valued cropland.

Phosphorus-based manure application limits were shown to be expensive to implement. In the P-based manure application scenarios, reduction of TP in the runoff was greater at the edge-of-field sites than at the watershed outlets. This was most likely related to the variance in soil P concentrations, rather than the scale of observation.

- The CEEOT simulation showed that P-based manure application limits were expensive because of increased manure hauling costs, even with a hauling distance of only 8 km.

- The 30-yr simulation showed the TP reduction at the edge-of-field (LLB site) was about 50% when manure application was based on a soil or agronomic P rate compared to the baseline scenario, for which manure was applied based on the AOPA NO_3-N rate.

- In the watershed simulations, agronomic P-based manure application resulted in TP reductions of about 1% at the watershed outlets for IFC and WHC. This small reduction may be related to the relatively few fields that receive manure in IFC and the fact that most soils were below agronomic P concentrations in both watersheds. In contrast, the LLB site had STP concentrations that were very high (>200 mg kg^{-1} STP).

All BMP scenarios resulted in negative net returns either from a decline in revenues or an increase in cost. The size of the representative farms affected the scale of the economic impact when they were reported on a per hectare basis.

- The economic impact of BMPs varied among farms depending on the individual characteristics of the farms and the extent to which the BMP was applied on-farm. When the economic results were reported on a per hectare basis, the size of the individual representative farms also affected the magnitude of the economic impact. Larger farms resulted in smaller economic impacts per hectare than smaller farms.

While detailed simulation capability provided the option of simulating complex combinations of practices, there were some limitations in comparison to the 'real world'.

- Development of the CEEOT model applications entailed micro-scale simulations, with more than 1000 subareas each in the IFC and WHC watersheds. Micro-scale simulations were deemed necessary because of the need to evaluate the field study BMP sites in each watershed. These micro-scale simulations were possible because of the combination of field- and watershed-scale environmental models and farm-level economic model, as well as the pre-processing routines that were developed to generate input files for each scenario. There were some challenges in validating at such a small scale.

- Model simulations of the field study BMPs required some modification, particularly when livestock were involved. Rather than modelling the physical presence of livestock, simulations involved changing the grazing practise such that cattle were rotated more or less frequently. Similarly, the model simulation of fencing or off-stream watering was for cattle exclusion. Bioengineering of riparian areas could not be simulated.

- In some cases, the simulated BMP would not be possible or practical to implement in the field. For example, manure incorporation on a windy day in IFC would result in topsoil losses, and as such, may not be a practical approach for manure management in the area. Similarly, the manure setbacks in the WHC Sub-watershed may make field operations very difficult or cumbersome. The modelled irrigation management at the LLB site would probably provide logistical challenges for the farmer to implement in terms of the field challenges and resource commitment.

Cost-effectiveness estimates provided insight into which scenario generated the greatest loss reduction per dollar spent. However, the most cost-effective scenario may not necessarily achieve the water quality goal.

- Cost-effectiveness values presented for all scenarios and indicators in each watershed showed that some scenarios will achieve the reductions for a given indicator much more cost-effectively than others. The most cost-effective scenario may actually entail a greater cost to land owners, but it is more cost-effective because the nutrient loss reduction is greater in proportion than the cost increase associated with that scenario.

- Cost-effectiveness estimates are an aid in targeting practices to achieve water quality goals at least cost. If the most cost-effective scenario does not achieve the water quality goal, either the second most cost-effective practice or a combination of the practices may be used in certain areas.

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9 APPENDICES

Appendix 1. Glossary of terms.

AOPA. Agricultural Operation Practices Act specifies acceptable manure application management standards for all farm operations in Alberta that handle manure.

Beneficial management practices. Any agricultural management practice that mitigates or minimizes negative effects and risks to the environment by maintaining or improving water, land and air quality, and biodiversity (AFRD 2006).

Buffer strip. A vegetative buffer placed downslope of a field to reduce sediment loss and reduce flow of nutrients or contaminants from the field to an adjacent water body.

Common water body. A significant accumulation of surface water that is shared by multiple landowners.

Grassed waterway. A natural or constructed channel established for transport of concentrated flow at safe velocities using adequate vegetation. Grass waterways are generally broad and shallow by design to move surface water across farmland without causing soil erosion (Green and Haney).

Hydrologic response units (HRUs). A basic computational unit used in SWAT that represents the areas within a watershed that generate similar or homogeneous hydrologic response to a given input. In general, areas representing an HRU have similar biophysical properties, primarily soil type, and land use.

Irrigation efficiency. The ratio between irrigation water actually utilized by growing crops and water diverted from a source (as a stream) in order to supply such irrigation water (Merriam Webster. Available at http://www.merriam-webster.com/dictionary/irrigation efficiency).

Reduced tillage. A tillage system that leaves about 15 to 30% of crop residue cover on the soil. In terms of tillage intensity, reduced tillage is between intensive tillage and no-tillage.

Rotational grazing. The shifting of livestock to different units of a pasture or range in regular sequence to permit the recovery and growth of the pasture plants after grazing (Merriam Webster. Available at http://www.merriam-webster.com/dictionary/rotation grazing).

Subarea. A basic computational unit used in APEX. It is similar to a HRU used for SWAT. A subarea represents an actual or virtual field or a portion thereof.

Wetland restoration. Restoration of original wetland hydrology, vegetation, or functions, usually at sites where wetlands existed previously, but where they have been impacted by prior or surrounding land use (http://oregonexplorer.info/willamette/WillametteBasinGlossary).

Appendix 2. SWAPP estimated annual average cumulative flow and sediment and nutrient losses at the outlet of each sub-basin for the Indianfarm Creek Watershed.

Table A 2.1. Indianfarm Creek Watershed sub-basin scale environmental results for Scenario 1 (baseline).

	Drainage area			Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets							
Sub-basin	Individual	Cumulative	Tributary (Tr.)	Flow ($m^3 s^{-1}$)	TSS (Mg)	ON	OP	NO_3-N	PO_4-P	TN	TP
	(ha)					(kg)					
27	737.9	737.9		0.035	1484.9	10398	1967	3467	795	13865	2762
22	1008.5	1746.4		0.066	368.4	9714	1770	4519	816	14233	2585
21	2209.8	3956.2		0.102	2143.7	17787	3561	17965	2876	35753	6437
18	74.1	74.1	Tr.1	0.001	0.9	196	36	407	156	603	193
19	56.0	130.1	Tr.1	0.004	8.9	289	47	712	258	1000	305
26	607.4	4693.7		0.154	2683.9	21926	4105	19572	3435	41498	7540
20	523.3	5217.0		0.196	2383.8	25079	4804	24234	5398	49313	10202
17	865.5	6082.5		0.197	3504.5	31293	5985	26079	5803	57372	11788
14	2156.0	8238.5		0.221	5147.1	35016	6544	27545	6013	62561	12556
13	23.8	8262.3		0.221	5953.3	35218	6570	27587	6046	62805	12616
16	18.8	18.8	Tr.2	0.000	0.1	10	2	11	2	22	4
25	1011.2	1030.0	Tr.2	0.014	235.2	4731	1252	4683	932	9414	2184
15	2.1	1032.1	Tr.2	0.014	173.5	4726	1251	4641	930	9366	2180
24	281.2	1313.3	Tr.2	0.018	105.8	5441	1359	4840	1061	10280	2420
12	10.6	1323.9	Tr.2	0.018	163.9	5545	1372	4819	1067	10364	2439
11	12.6	9598.8		0.238	3823.3	40467	7857	31927	7047	72394	14904
9	54.4	54.4	Tr.3	0.001	5.1	55	9	37	35	92	44
10	5.9	60.2	Tr.3	0.001	5.2	51	8	31	35	82	43
8	9.6	9668.6		0.239	4019.9	40521	7865	31953	7091	72474	14956
7	9.5	9678.1		0.240	4028.0	40775	7909	32055	7117	72830	15026
4	19.4	19.4	Tr.4	0.000	3.2	47	6	6	3	52	9
3	21.5	41.0	Tr.4	0.000	1.9	25	7	56	15	81	22
23	1332.0	1373.0	Tr.4	0.006	677.3	585	88	1637	176	2223	264
2	8.6	1381.5	Tr.4	0.006	20.5	579	84	1630	171	2209	255
5	1957.6	1957.6	Tr.5	0.127	10576.3	21614	3306	6660	1445	28274	4751
6	67.1	67.1	Tr.6	0.001	2.2	150	38	133	46	282	84
1	1060.9	14145.2		0.443	19833.2	70158	12191	41978	9212	112137	21403

Table A 2.2. Indianfarm Creek Watershed sub-basin scale environmental results for Scenario 1 (baseline).

Sub-basin	Drainage area: Individual (ha)	Drainage area: Cumulative (ha)	Tributary (Tr.)	Flow (mm)	TSS ($Mg\ ha^{-1}$)	ON ($kg\ ha^{-1}$)	OP ($kg\ ha^{-1}$)	NO_3-N ($kg\ ha^{-1}$)	PO_4-P ($kg\ ha^{-1}$)	TN ($kg\ ha^{-1}$)	TP ($kg\ ha^{-1}$)
				Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets							
27	737.9	737.9		149	2.012	14.1	2.7	4.7	1.1	18.8	3.7
22	1008.5	1746.4		118	0.211	5.6	1.0	2.6	0.5	8.1	1.5
21	2209.8	3956.2		81	0.542	4.5	0.9	4.5	0.7	9.0	1.6
18	74.1	74.1	Tr.1	56	0.012	2.6	0.5	5.5	2.1	8.1	2.6
19	56	130.1	Tr.1	90	0.068	2.2	0.4	5.5	2.0	7.7	2.3
26	607.4	4693.7		104	0.572	4.7	0.9	4.2	0.7	8.8	1.6
20	523.3	5217		118	0.457	4.8	0.9	4.6	1.0	9.5	2.0
17	865.5	6082.5		102	0.576	5.1	1.0	4.3	1.0	9.4	1.9
14	2156	8238.5		85	0.625	4.3	0.8	3.3	0.7	7.6	1.5
13	23.8	8262.3		84	0.721	4.3	0.8	3.3	0.7	7.6	1.5
16	18.8	18.8	Tr.2	15	0.006	0.5	0.1	0.6	0.1	1.2	0.2
25	1011.2	1030	Tr.2	44	0.228	4.6	1.2	4.5	0.9	9.1	2.1
15	2.1	1032.1	Tr.2	44	0.168	4.6	1.2	4.5	0.9	9.1	2.1
24	281.2	1313.3	Tr.2	44	0.081	4.1	1.0	3.7	0.8	7.8	1.8
12	10.6	1323.9	Tr.2	44	0.124	4.2	1.0	3.6	0.8	7.8	1.8
11	12.6	9598.8		78	0.398	4.2	0.8	3.3	0.7	7.5	1.6
9	54.4	54.4	Tr.3	60	0.094	1.0	0.2	0.7	0.7	1.7	0.8
10	5.9	60.2	Tr.3	56	0.086	0.8	0.1	0.5	0.6	1.4	0.7
8	9.6	9668.6		78	0.416	4.2	0.8	3.3	0.7	7.5	1.5
7	9.5	9678.1		78	0.416	4.2	0.8	3.3	0.7	7.5	1.6
4	19.4	19.4	Tr.4	21	0.166	2.4	0.3	0.3	0.2	2.7	0.5
3	21.5	41	Tr.4	14	0.046	0.6	0.2	1.4	0.4	2.0	0.5
23	1332	1373	Tr.4	14	0.493	0.4	0.1	1.2	0.1	1.6	0.2
2	8.6	1381.5	Tr.4	14	0.015	0.4	0.1	1.2	0.1	1.6	0.2
5	1957.6	1957.6	Tr.5	205	5.403	11.0	1.7	3.4	0.7	14.4	2.4
6	67.1	67.1	Tr.6	51	0.032	2.2	0.6	2.0	0.7	4.2	1.2
1	1060.9	14145.2		99	1.402	5.0	0.9	3.0	0.7	7.9	1.5

Table A2.3. Pred icted baseline 30-yr averages for flow, total suspended solids (TSS), and fractions of nitrogen and phosphorus for the beneficial management practices (BMP) sites in Indianfarm Creek Watershed.

BMP site	Sub-area ID	Subarea size (ha)	Sub-basin ID	Flow (mm)	TSS (Mg ha^{-1})	TN	TP	ON	OP	NO_3^-N	PO_4-P
						---------------------	(kg ha^{-1})			------------------------	
DMF	116	13.8	4	28.1	0.24	4.43	0.68	3.10	0.43	1.33	0.25
DMF	130	2.3	4	26.6	0.34	4.05	0.62	2.77	0.39	1.28	0.23
DMF	390	1.4	4	11.9	0.04	0.95	0.05	0.12	0.02	0.83	0.03
IMP	960	2.6	2	59.0	0.38	8.19	0.90	2.75	0.57	5.44	0.33
IMP	2400	0.4	2	80.7	2.36	12.87	1.09	8.62	1.03	4.25	0.06
IMP	104	2.0	2	61.3	0.15	7.76	0.66	1.37	0.29	6.39	0.37
NMF	1401	2.8	6	52.1	0.06	4.50	1.45	1.96	0.64	2.54	0.81
NMF	299	3.1	6	64.1	0.28	8.39	2.29	4.44	1.29	3.95	1.00
NMF	358	2.2	6	57.3	0.16	6.83	2.08	3.60	1.10	3.23	0.98
NMF	327	1.8	6	52.6	0.06	4.56	1.47	1.98	0.65	2.58	0.82
NMF	9	15.8	6	40.7	0.00	3.13	1.33	1.59	0.49	1.54	0.84
NMF	319	40.0	6	44.4	0.03	3.40	1.29	1.61	0.51	1.79	0.78
PST	313	2.2	10	29.4	0.08	2.66	1.31	1.57	0.38	1.09	0.93
PST	968	3.4	10	20.0	0.29	4.07	1.20	3.18	0.69	0.89	0.51
PST	183	12.9	1	194.2	2.39	5.86	0.68	2.70	0.49	3.16	0.19
PST	316	2.1	1	191.3	0.83	14.92	2.24	11.18	1.82	3.74	0.42
PST	972	14.2	1	194.2	2.37	6.04	0.72	2.89	0.53	3.15	0.19
PST	309	5.5	1	197.9	0.27	5.39	0.85	2.44	0.56	2.95	0.29
PST	197	19.0	1	194.7	1.80	3.96	0.40	0.90	0.25	3.06	0.15
PST	180	0.6	7	160.3	1.57	49.84	8.60	34.59	6.55	15.25	2.05
PST	967	6.7	7	160.3	1.72	53.49	9.21	37.87	7.15	15.62	2.06
PST	970	4.0	8	33.5	0.35	4.73	1.31	3.55	0.70	1.18	0.61
PST	196	3.2	8	37.2	0.03	2.28	1.16	0.99	0.28	1.29	0.88
PST	314	0.6	9	58.3	0.09	2.46	1.06	0.84	0.26	1.62	0.80
PST	969	0.7	9	58.3	0.11	2.48	1.06	0.86	0.26	1.62	0.80
PST	971	5.3	11	44.4	0.52	8.45	1.41	5.96	1.07	2.49	0.34
SMF	714	6.2	19	132.6	0.15	12.92	2.12	2.51	0.77	10.41	1.35
WIN	332	0.5	9	81.6	0.04	12.87	0.08	0.12	0.01	12.75	0.07
WIN	975	0.9	13	71.0	0.29	4.29	1.27	2.88	0.39	1.41	0.88
WIN	993	7.4	13	72.0	0.82	12.02	2.31	9.47	1.42	2.55	0.89
WIN	1400	0.2	13	72.0	0.83	12.06	2.30	9.51	1.42	2.55	0.88
WIN	989	27.0	14	40.0	0.61	2.81	0.44	1.78	0.31	1.03	0.13
WIN	991	1.1	11	40.0	0.61	2.87	0.44	1.83	0.31	1.04	0.13
WIN	1000	5.5	24	45.9	0.39	9.61	1.15	5.40	0.88	4.21	0.27
WIN	993	7.4	13	53.7	0.10	4.97	0.95	1.83	0.54	3.14	0.41
WIN	994	5.2	24	72.0	0.82	12.02	2.31	9.47	1.42	2.55	0.89
WIN	995	6.3	14	47.6	0.63	12.99	1.62	8.74	1.32	4.25	0.30
WIN	998	3.4	11	59.6	1.85	29.31	3.86	25.70	3.41	3.61	0.45
WIN	999	3.5	12	54.9	0.82	15.02	2.34	12.17	1.80	2.85	0.54

Table A 2.4. Indianfarm Creek Watershed sub-basin scale environmental results for Scenario 2 (field study BMPs): Flow and sediment and nutrient losses.

	Drainage area			Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets							
Sub-basin	Individual	Cumulative	Tributary (Tr.)	Flow ($m^3 s^{-1}$)	TSS (Mg)	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------					------- (kg) -------					
27	737.9	737.9		0.035	1484.9	10398	1967	3467	795	13865	2762
22	1008.5	1746.4		0.066	368.4	9714	1770	4519	816	14233	2585
21	2209.8	3956.2		0.102	2143.7	17787	3561	17965	2876	35753	6437
18	74.1	74.1	Tr.1	0.001	0.9	196	36	407	156	603	193
19	56.0	130.1	Tr.1	0.004	8.9	264	39	606	197	870	236
26	607.4	4693.7		0.154	2681.8	21900	4097	19434	3372	41334	7469
20	523.3	5217.0		0.196	2382.4	25053	4796	24096	5335	49149	10131
17	865.5	6082.5		0.197	3502.9	31269	5977	25945	5733	57215	11710
14	2156.0	8238.5		0.221	5142.1	34946	6528	27407	5943	62353	12471
13	23.8	8262.3		0.221	5939.0	35001	6535	27441	5971	62442	12506
16	18.8	18.8	Tr.2	0.000	0.1	10	2	11	2	22	4
25	1011.2	1030.0	Tr.2	0.014	235.2	4731	1252	4683	932	9414	2184
15	2.1	1032.1	Tr.2	0.014	173.5	4726	1251	4635	930	9361	2180
24	281.2	1313.3	Tr.2	0.018	106.0	5441	1359	4742	1058	10184	2418
12	10.6	1323.9	Tr.2	0.018	164.1	5546	1373	4733	1065	10279	2438
11	12.6	9598.8		0.238	3837.8	40664	7869	31760	6977	72424	14845
9	54.4	54.4	Tr.3	0.001	5.2	40	3	29	26	68	29
10	5.9	60.2	Tr.3	0.001	5.2	36	4	39	25	75	29
8	9.6	9668.6		0.239	4032.9	40795	7891	31843	7021	72638	14911
7	9.5	9678.1		0.240	4033.2	40785	7889	31877	7024	72662	14912
4	19.4	19.4	Tr.4	0.000	2.9	38	5	6	3	45	7
3	21.5	41.0	Tr.4	0.000	1.8	21	6	57	15	78	21
23	1332.0	1373.0	Tr.4	0.006	677.2	581	88	1637	176	2219	263
2	8.6	1381.5	Tr.4	0.006	20.5	570	82	1625	171	2195	253
5	1957.6	1957.6	Tr.5	0.128	10597.1	21386	3294	5056	1332	26442	4625
6	67.1	67.1	Tr.6	0.001	2.2	141	32	130	41	271	73
1	1060.9	14145.2		0.444	19827.8	69934	12143	40243	9001	110178	21145

Table A 2.5. Indianfarm Creek Watershed sub-basin scale environmental results for Scenario 2 (field study BMPs): Percent change relative to the baseline.

Sub-basin	Drainage area: Individual	Drainage area: Cumulative	Tributary (Tr.)	Changes of flow and sediment and nutrient losses from baseline scenario at the sub-basin outlets: Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			-- (%) --							
27	737.9	737.9		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1008.5	1746.4		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	2209.8	3956.2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	74.1	74.1	Tr.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	56.0	130.1	Tr.1	-0.9	0.4	-8.5	-15.9	-14.9	-23.8	-13.1	-22.5
26	607.4	4693.7		0.0	-0.1	-0.1	-0.2	-0.7	-1.8	-0.4	-0.9
20	523.3	5217.0		0.0	-0.1	-0.1	-0.2	-0.6	-1.2	-0.3	-0.7
17	865.5	6082.5		0.0	0.0	-0.1	-0.1	-0.5	-1.2	-0.3	-0.7
14	2156.0	8238.5		0.0	-0.1	-0.2	-0.2	-0.5	-1.2	-0.3	-0.7
13	23.8	8262.3		-0.1	-0.2	-0.6	-0.5	-0.5	-1.2	-0.6	-0.9
16	18.8	18.8	Tr.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	1011.2	1030.0	Tr.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	2.1	1032.1	Tr.2	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1	0.0
24	281.2	1313.3	Tr.2	0.0	0.2	0.0	0.1	-2.0	-0.2	-0.9	-0.1
12	10.6	1323.9	Tr.2	0.0	0.1	0.0	0.1	-1.8	-0.2	-0.8	-0.1
11	12.6	9598.8		0.0	0.4	0.5	0.2	-0.5	-1.0	0.0	-0.4
9	54.4	54.4	Tr.3	-0.8	1.9	-28.5	-64.9	-21.4	-28.0	-25.7	-35.4
10	5.9	60.2	Tr.3	-0.7	0.7	-28.8	-51.8	24.5	-27.9	-8.6	-32.4
8	9.6	9668.6		0.0	0.3	0.7	0.3	-0.3	-1.0	0.2	-0.3
7	9.5	9678.1		0.0	0.1	0.0	-0.3	-0.6	-1.3	-0.2	-0.8
4	19.4	19.4	Tr.4	-6.3	-11.3	-18.0	-20.0	15.0	-17.8	-14.5	-19.2
3	21.5	41.0	Tr.4	-4.3	-6.3	-13.7	-6.3	0.8	-2.1	-3.6	-3.4
23	1332.0	1373.0	Tr.4	-0.1	0.0	-0.7	-0.6	0.0	-0.2	-0.2	-0.3
2	8.6	1381.5	Tr.4	-0.4	-0.2	-1.6	-2.1	-0.3	-0.5	-0.6	-1.1
5	1957.6	1957.6	Tr.5	0.2	0.2	-1.1	-0.4	-24.1	-7.8	-6.5	-2.6
6	67.1	67.1	Tr.6	-0.9	0.2	-6.1	-14.7	-2.0	-11.3	-4.2	-12.8
1	1060.9	14145.2		0.0	0.0	-0.3	-0.4	-4.1	-2.3	-1.8	-1.2

Table A2.6. Predicted Scenario 2 30-yr averages for flow, total suspended solids (TSS), and fractions of nitrogen and phosphorus for the beneficial management practices (BMP) sites in Indianfarm Creek Watershed.

BMP site	Sub-area ID	Subarea size (ha)	Sub-basin ID	Flow (mm)	TSS ($Mg\ ha^{-1}$)	TN	TP	ON	OP	NO_3^-N	PO_4-P
						($kg\ ha^{-1}$)					
DMF	116	13.8	4	24.6	0.22	3.88	0.55	2.61	0.35	1.27	0.20
DMF	130	2.3	4	23.5	0.31	3.38	0.46	2.15	0.29	1.23	0.17
DMF	390	1.4	4	11.9	0.04	0.95	0.05	0.12	0.02	0.83	0.03
IMP	960	2.6	2	54.0	0.35	7.21	0.71	2.03	0.41	5.18	0.30
IMP	2400	0.4	2	80.7	2.36	12.87	1.09	8.62	1.03	4.25	0.06
IMP	104	2.0	2	61.3	0.15	7.76	0.66	1.37	0.29	6.39	0.37
NMF	1401	2.8	6	51.8	0.06	4.28	1.06	1.87	0.51	2.41	0.55
NMF	299	3.1	6	63.9	0.28	8.29	2.06	4.40	1.20	3.89	0.86
NMF	358	2.2	6	57.0	0.17	6.73	1.73	3.60	0.97	3.13	0.76
NMF	327	1.8	6	52.3	0.07	4.39	1.09	1.93	0.52	2.46	0.57
NMF	9	15.8	6	40.2	0.02	2.89	0.67	1.54	0.21	1.35	0.46
NMF	319	40	6	44.1	0.04	3.17	0.78	1.54	0.34	1.63	0.44
PST	313	2.2	10	11.7	0.06	1.05	0.38	0.36	0.29	0.69	0.09
PST	968	3.4	10	19.2	0.28	5.28	1.16	2.84	0.78	2.44	0.38
PST	183	12.9	1	192.8	2.39	6.02	0.67	2.81	0.48	3.21	0.19
PST	316	2.1	1	189.8	0.81	14.01	2.09	10.40	1.71	3.61	0.38
PST	972	14.2	1	192.8	2.37	6.18	0.70	2.97	0.51	3.21	0.19
PST	309	5.5	1	191.0	0.30	5.96	0.86	2.53	0.56	3.43	0.30
PST	197	19.0	1	193.4	1.81	4.48	0.42	1.33	0.26	3.15	0.16
PST	180	0.6	7	171.2	0.75	14.22	1.62	6.77	1.36	7.45	0.26
PST	967	6.7	7	173.0	0.82	14.33	1.59	7.29	1.44	7.04	0.15
PST	970	4.0	8	54.8	0.62	16.89	3.33	10.96	2.21	5.93	1.12
PST	196	3.2	8	48.0	0.04	5.77	1.63	0.77	0.48	5.00	1.15
PST	314	0.6	9	57.9	0.10	1.98	0.54	0.64	0.12	1.34	0.42
PST	969	0.7	9	57.9	0.13	1.97	0.53	0.64	0.12	1.33	0.41
PST	971	5.3	11	61.6	1.62	39.59	4.87	33.62	4.17	5.97	0.70
SMF	714	6.2	19	130.4	0.15	10.05	1.25	2.09	0.64	7.96	0.61
WIN	332	0.5	9	59.8	0.01	0.77	0.04	0.04	0.01	0.73	0.03
WIN	975	0.9	13	70.4	0.30	4.20	1.24	2.82	0.37	1.38	0.87
WIN	993	7.4	13	62.0	0.56	6.73	1.48	4.57	0.74	2.16	0.74
WIN	1400	0.2	13	61.9	0.56	6.75	1.48	4.59	0.75	2.16	0.73
WIN	989	27.0	14	39.9	0.61	2.80	0.43	1.77	0.30	1.03	0.13
WIN	991	1.1	11	40.0	0.61	2.85	0.44	1.82	0.31	1.03	0.13
WIN	1000	5.5	24	45.9	0.38	8.33	1.14	5.36	0.88	2.97	0.26
WIN	993	7.4	13	53.7	0.10	4.93	0.93	1.79	0.53	3.14	0.40
WIN	**994**	**5.2**	**24**	**62.0**	**0.56**	**6.73**	**1.48**	**4.57**	**0.74**	**2.16**	**0.74**
WIN	995	6.3	14	47.7	0.63	11.94	1.62	8.75	1.33	3.19	0.29
WIN	998	3.4	11	59.6	1.85	29.33	3.86	25.70	3.41	3.63	0.45
WIN	999	3.5	12	54.9	0.82	15.00	2.32	12.16	1.80	2.84	0.52

Table A2.7. Indianfarm Creek Watershed sub-basin scale environmental results for Scenario 3 (AOPA): Flow and sediment and nutrient losses.

Sub-basin	Drainage area: Individual	Drainage area: Cumulative	Tributary (Tr.)	Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets: Flow ($m^3 s^{-1}$)	TSS (Mg)	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------					---------- (kg) ----------					
27	737.9	737.9		0.035	1484.9	10398	1967	3467	795	13865	2762
22	1008.5	1746.4		0.066	368.4	9714	1770	4519	816	14233	2585
21	2209.8	3956.2		0.102	2143.7	17787	3561	17965	2876	35753	6437
18	74.1	74.1	Tr.1	0.001	0.9	189	36	407	150	595	186
19	56.0	130.1	Tr.1	0.004	8.9	278	47	712	250	990	297
26	607.4	4693.7		0.154	2678.5	21293	4088	19572	3380	40865	7468
20	523.3	5217.0		0.195	2378.2	24447	4787	24234	5343	48681	10130
17	865.5	6082.5		0.197	3500.7	30707	5971	26078	5752	56785	11723
14	2156.0	8238.5		0.221	5147.1	34411	6529	27550	5950	61961	12478
13	23.8	8262.3		0.221	5951.4	34614	6555	27592	5979	62206	12533
16	18.8	18.8	Tr.2	0.000	0.1	10	2	11	2	22	4
25	1011.2	1030.0	Tr.2	0.014	235.2	4731	1252	4683	932	9414	2184
15	2.1	1032.1	Tr.2	0.014	173.5	4726	1251	4641	930	9366	2180
24	281.2	1313.3	Tr.2	0.018	105.8	5441	1359	4840	1061	10280	2420
12	10.6	1323.9	Tr.2	0.018	163.9	5545	1372	4819	1067	10364	2439
11	12.6	9598.8		0.238	3822.8	39863	7842	31932	6980	71795	14822
9	54.4	54.4	Tr.3	0.001	5.2	39	3	27	26	66	30
10	5.9	60.2	Tr.3	0.001	5.2	38	3	22	27	60	30
8	9.6	9668.6		0.239	4019.2	39905	7845	31948	7016	71854	14861
7	9.5	9678.1		0.240	4027.3	40159	7889	32051	7042	72210	14931
4	19.4	19.4	Tr.4	0.000	3.3	15	1	5	2	21	3
3	21.5	41.0	Tr.4	0.000	1.9	11	5	56	14	68	19
23	1332.0	1373.0	Tr.4	0.006	677.3	574	86	1637	175	2211	262
2	8.6	1381.5	Tr.4	0.006	20.5	568	82	1630	171	2197	253
5	1957.6	1957.6	Tr.5	0.127	10576.8	21357	3294	6659	1408	28016	4702
6	67.1	67.1	Tr.6	0.001	2.2	147	33	124	42	271	74
1	1060.9	14145.2		0.443	19830.0	69277	12152	41963	9096	111240	21248

Table A 2.8. Indianfarm Creek Watershed sub-basin scale environmental results for Scenario 3 (AOPA): Percent change relative to the baseline.

	Drainage area			Changes of flow and sediment and nutrient losses from baseline scenario at the sub-basin outlets							
Sub-basin	Individual	Cumulative	Tributary (Tr.)	Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	--------(ha)--------			(%)							
27	737.9	737.9		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1008.5	1746.4		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	2209.8	3956.2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	74.1	74.1	Tr.1	0.1	1.4	-3.9	-0.8	0.0	-4.3	-1.3	-3.6
19	56.0	130.1	Tr.1	0.0	0.4	-3.9	-0.5	0.1	-2.9	-1.1	-2.5
26	607.4	4693.7		-0.2	-0.2	-2.9	-0.4	0.0	-1.6	-1.5	-1.0
20	523.3	5217.0		-0.1	-0.2	-2.5	-0.3	0.0	-1.0	-1.3	-0.7
17	865.5	6082.5		-0.1	-0.1	-1.9	-0.2	0.0	-0.9	-1.0	-0.6
14	2156.0	8238.5		-0.1	0.0	-1.7	-0.2	0.0	-1.1	-1.0	-0.6
13	23.8	8262.3		-0.1	0.0	-1.7	-0.2	0.0	-1.1	-1.0	-0.7
16	18.8	18.8	Tr.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	1011.2	1030.0	Tr.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	2.1	1032.1	Tr.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	281.2	1313.3	Tr.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	10.6	1323.9	Tr.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	12.6	9598.8		-0.1	0.0	-1.5	-0.2	0.0	-1.0	-0.8	-0.6
9	54.4	54.4	Tr.3	-0.1	1.0	-28.8	-61.4	-26.8	-26.3	-28.0	-33.3
10	5.9	60.2	Tr.3	-0.1	1.0	-25.4	-59.1	-29.5	-22.6	-27.0	-29.4
8	9.6	9668.6		-0.1	0.0	-1.5	-0.3	0.0	-1.1	-0.9	-0.6
7	9.5	9678.1		-0.1	0.0	-1.5	-0.3	0.0	-1.1	-0.9	-0.6
4	19.4	19.4	Tr.4	0.4	2.1	-67.0	-86.1	-3.7	-40.0	-60.3	-68.8
3	21.5	41.0	Tr.4	0.3	0.7	-53.7	-31.0	-0.3	-6.6	-16.5	-14.3
23	1332.0	1373.0	Tr.4	0.0	0.0	-2.0	-2.1	0.0	-0.5	-0.5	-1.0
2	8.6	1381.5	Tr.4	0.0	0.0	-1.9	-2.1	0.0	-0.5	-0.5	-1.0
5	1957.6	1957.6	Tr.5	0.0	0.0	-1.2	-0.4	0.0	-2.5	-0.9	-1.0
6	67.1	67.1	Tr.6	-0.7	0.5	-1.6	-13.5	-6.5	-8.9	-3.9	-11.0
1	1060.9	14145.2		0.0	0.0	-1.3	-0.3	0.0	-1.3	-0.8	-0.7

Table A 2.9. Indianfarm Creek Watershed sub-basin scale environmental results for Scenario 4: Flow and sediment and nutrient losses.

	Drainage area			Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets							
Sub-basin	Individual	Cumulative	Tributary (Tr.)	Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			($m^3 s^{-1}$)	(Mg)	---------- (kg) ----------					
27	737.9	737.9		0.033	137.4	1368	345	3098	782	4465	1127
22	1008.5	1746.4		0.061	262.8	1382	319	3968	788	5350	1107
21	2209.8	3956.2		0.095	505.7	3404	888	15478	2762	18882	3650
18	74.1	74.1	Tr.1	0.001	0.3	127	25	335	139	462	164
19	56.0	130.1	Tr.1	0.003	5.6	175	29	665	249	839	278
26	607.4	4693.7		0.144	657.5	3934	975	17011	3255	20945	4229
20	523.3	5217.0		0.183	742.1	4543	1173	21285	5157	25828	6331
17	865.5	6082.5		0.183	2915.9	5113	1681	22894	5540	28007	7221
14	2156.0	8238.5		0.201	3814.8	5184	1677	24057	5719	29241	7397
13	23.8	8262.3		0.202	4822.2	5246	1686	24097	5748	29343	7434
16	18.8	18.8	Tr.2	0.000	0.0	6	1	12	2	18	4
25	1011.2	1030.0	Tr.2	0.012	23.7	1170	660	3875	883	5045	1543
15	2.1	1032.1	Tr.2	0.012	73.1	1168	658	3877	883	5044	1541
24	281.2	1313.3	Tr.2	0.015	54.6	1253	665	4031	1005	5284	1671
12	10.6	1323.9	Tr.2	0.015	105.3	1257	666	4033	1011	5289	1677
11	12.6	9598.8		0.215	3426.3	6408	2304	27714	6684	34121	8988
9	54.4	54.4	Tr.3	0.001	2.3	7	1	32	25	39	26
10	5.9	60.2	Tr.3	0.001	2.3	7	1	29	27	36	27
8	9.6	9668.6		0.216	3603.7	6417	2304	27740	6720	34158	9025
7	9.5	9678.1		0.217	3605.4	6473	2316	27836	6746	34309	9062
4	19.4	19.4	Tr.4	0.000	0.8	1	0	4	2	5	2
3	21.5	41.0	Tr.4	0.000	1.1	1	0	46	12	47	13
23	1332.0	1373.0	Tr.4	0.003	142.7	24	3	1502	158	1526	161
2	8.6	1381.5	Tr.4	0.003	17.0	24	3	1464	151	1488	154
5	1957.6	1957.6	Tr.5	0.119	1539.8	395	52	5988	1359	6382	1411
6	67.1	67.1	Tr.6	0.001	0.8	108	25	123	40	231	65
1	1060.9	14145.2		0.408	14913.6	7430	2430	36802	8714	44232	11144

Table A 2.10. Indianfarm Creek Watershed sub-basin scale environmental results for Scenario 4: Percent change relative to the baseline.

Sub-basin	Drainage area: Individual	Drainage area: Cumulative	Tributary (Tr.)	Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			---------- (%) ----------							
27	737.9	737.9		-5.4	-90.8	-86.9	-82.5	-10.6	-1.5	-67.8	-59.2
22	1008.5	1746.4		-6.7	-28.7	-85.8	-82.0	-12.2	-3.4	-62.4	-57.2
21	2209.8	3956.2		-7.3	-76.4	-80.9	-75.1	-13.9	-4.0	-47.2	-43.3
18	74.1	74.1	Tr.1	-17.3	-69.5	-35.5	-31.4	-17.6	-11.0	-23.4	-14.9
19	56.0	130.1	Tr.1	-6.8	-36.9	-39.6	-37.2	-6.6	-3.4	-16.1	-8.6
26	607.4	4693.7		-6.6	-75.5	-82.1	-76.3	-13.1	-5.3	-49.5	-43.9
20	523.3	5217.0		-6.4	-68.9	-81.9	-75.6	-12.2	-4.5	-47.6	-38.0
17	865.5	6082.5		-7.4	-16.8	-83.7	-71.9	-12.2	-4.5	-51.2	-38.8
14	2156.0	8238.5		-9.0	-25.9	-85.2	-74.4	-12.7	-4.9	-53.3	-41.1
13	23.8	8262.3		-9.0	-19.0	-85.1	-74.3	-12.7	-4.9	-53.3	-41.1
16	18.8	18.8	Tr.2	-3.2	-57.5	-40.5	-34.4	3.3	-0.3	-17.5	-15.3
25	1011.2	1030.0	Tr.2	-19.6	-89.9	-75.3	-47.3	-17.3	-5.2	-46.4	-29.4
15	2.1	1032.1	Tr.2	-19.6	-57.9	-75.3	-47.4	-16.5	-5.0	-46.2	-29.3
24	281.2	1313.3	Tr.2	-18.5	-48.4	-77.0	-51.0	-16.7	-5.3	-48.6	-31.0
12	10.6	1323.9	Tr.2	-18.4	-35.8	-77.3	-51.5	-16.3	-5.2	-49.0	-31.2
11	12.6	9598.8		-9.7	-10.4	-84.2	-70.7	-13.2	-5.2	-52.9	-39.7
9	54.4	54.4	Tr.3	-2.3	-54.3	-86.8	-93.8	-12.3	-29.4	-57.2	-42.3
10	5.9	60.2	Tr.3	-2.6	-54.8	-85.7	-93.1	-8.0	-23.4	-56.3	-36.5
8	9.6	9668.6		-9.7	-10.4	-84.2	-70.7	-13.2	-5.2	-52.9	-39.7
7	9.5	9678.1		-9.6	-10.5	-84.1	-70.7	-13.2	-5.2	-52.9	-39.7
4	19.4	19.4	Tr.4	-22.8	-73.8	-97.6	-98.7	-26.1	-54.3	-90.0	-82.0
3	21.5	41.0	Tr.4	-20.5	-42.8	-95.2	-95.0	-17.9	-17.7	-41.4	-42.1
23	1332.0	1373.0	Tr.4	-44.9	-78.9	-95.9	-96.4	-8.2	-10.3	-31.3	-39.0
2	8.6	1381.5	Tr.4	-44.4	-17.3	-95.9	-96.7	-10.2	-12.1	-32.6	-39.8
5	1957.6	1957.6	Tr.5	-6.4	-85.4	-98.2	-98.4	-10.1	-5.9	-77.4	-70.3
6	67.1	67.1	Tr.6	-3.7	-63.7	-28.2	-33.4	-7.3	-13.4	-18.3	-22.5
1	1060.9	14145.2		-8.1	-24.8	-89.4	-80.1	-12.3	-5.4	-60.6	-47.9

Columns Flow to TP: Changes of flow and sediment and nutrient losses from baseline scenario at the sub-basin outlets

Table A2.11. Indianfarm Creek Watershed sub-basin scale environmental results for Scenario 5: Flow and sediment and nutrient losses.

Sub-basin	Drainage area: Individual	Drainage area: Cumulative	Tributary (Tr.)	Flow ($m^3 s^{-1}$)	TSS (Mg)	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------				Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets	---------- (kg) ----------					
27	737.9	737.9		0.033	137.4	1368	345	3098	782	4465	1127
22	1008.5	1746.4		0.061	262.8	1382	319	3968	788	5350	1107
21	2209.8	3956.2		0.095	505.7	3404	888	15478	2762	18882	3650
18	74.1	74.1	Tr.1	0.001	0.3	118	25	335	134	453	159
19	56.0	130.1	Tr.1	0.003	5.7	165	30	681	236	846	266
26	607.4	4693.7		0.144	658.0	3923	975	17026	3132	20949	4107
20	523.3	5217.0		0.183	742.5	4532	1174	21300	5034	25832	6208
17	865.5	6082.5		0.183	2916.5	5103	1681	22904	5431	28007	7112
14	2156.0	8238.5		0.201	3816.4	5175	1678	24068	5612	29242	7289
13	23.8	8262.3		0.202	4824.4	5236	1686	24108	5640	29344	7326
16	18.8	18.8	Tr.2	0.000	0.0	6	1	12	2	18	4
25	1011.2	1030.0	Tr.2	0.012	23.7	1170	660	3875	883	5045	1543
15	2.1	1032.1	Tr.2	0.012	73.1	1168	658	3877	883	5044	1541
24	281.2	1313.3	Tr.2	0.015	54.6	1253	665	4031	1005	5284	1671
12	10.6	1323.9	Tr.2	0.015	105.3	1257	666	4033	1011	5289	1677
11	12.6	9598.8		0.215	3428.0	6398	2304	27724	6576	34122	8880
9	54.4	54.4	Tr.3	0.001	2.3	8	1	24	22	32	22
10	5.9	60.2	Tr.3	0.001	2.3	8	1	21	24	29	25
8	9.6	9668.6		0.216	3605.3	6408	2305	27744	6610	34152	8915
7	9.5	9678.1		0.217	3607.1	6463	2316	27839	6635	34302	8951
4	19.4	19.4	Tr.4	0.000	0.8	1	0	4	1	5	1
3	21.5	41.0	Tr.4	0.000	1.1	1	0	46	12	47	12
23	1332.0	1373.0	Tr.4	0.003	142.7	24	3	1502	158	1526	161
2	8.6	1381.5	Tr.4	0.003	17.0	24	3	1464	151	1488	153
5	1957.6	1957.6	Tr.5	0.119	1539.8	392	52	5988	1317	6380	1370
6	67.1	67.1	Tr.6	0.001	0.8	112	26	116	37	229	63
1	1060.9	14145.2		0.408	14911.4	7423	2432	36798	8561	44221	10992

Table A2.12. Indianfarm Creek Watershed sub-basin scale environmental results for Scenario 5: Percent change relative to the baseline.

Sub-basin	Drainage area: Individual	Drainage area: Cumulative	Tributary	Changes of flow and sediment and nutrient losses from baseline scenario at the sub-basin outlets: Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	--------(ha)--------		(Tr.)	----------	----------	----------	----------	(%)	----------	----------	----------
27	737.9	737.9		-5.4	-90.8	-86.9	-82.5	-10.6	-1.5	-67.8	-59.2
22	1008.5	1746.4		-6.7	-28.7	-85.8	-82.0	-12.2	-3.4	-62.4	-57.2
21	2209.8	3956.2		-7.3	-76.4	-80.9	-75.1	-13.9	-4.0	-47.2	-43.3
18	74.1	74.1	Tr.1	-17.4	-67.1	-39.8	-31.6	-17.6	-14.1	-24.8	-17.4
19	56.0	130.1	Tr.1	-6.9	-36.0	-42.9	-36.0	-4.3	-8.4	-15.5	-12.6
26	607.4	4693.7		-6.6	-75.5	-82.1	-76.2	-13.0	-8.8	-49.5	-45.5
20	523.3	5217.0		-6.4	-68.9	-81.9	-75.6	-12.1	-6.7	-47.6	-39.2
17	865.5	6082.5		-7.3	-16.8	-83.7	-71.9	-12.2	-6.4	-51.2	-39.7
14	2156.0	8238.5		-8.9	-25.9	-85.2	-74.4	-12.6	-6.7	-53.3	-42.0
13	23.8	8262.3		-8.9	-19.0	-85.1	-74.3	-12.6	-6.7	-53.3	-41.9
16	18.8	18.8	Tr.2	-3.2	-57.5	-40.5	-34.4	3.3	-0.3	-17.5	-15.3
25	1011.2	1030.0	Tr.2	-19.6	-89.9	-75.3	-47.3	-17.3	-5.2	-46.4	-29.4
15	2.1	1032.1	Tr.2	-19.6	-57.9	-75.3	-47.4	-16.5	-5.0	-46.2	-29.3
24	281.2	1313.3	Tr.2	-18.5	-48.4	-77.0	-51.0	-16.7	-5.3	-48.6	-31.0
12	10.6	1323.9	Tr.2	-18.4	-35.8	-77.3	-51.5	-16.3	-5.2	-49.0	-31.2
11	12.6	9598.8		-9.7	-10.3	-84.2	-70.7	-13.2	-6.7	-52.9	-40.4
9	54.4	54.4	Tr.3	-5.3	-54.6	-86.2	-92.0	-34.0	-39.0	-65.4	-49.6
10	5.9	60.2	Tr.3	-5.5	-55.1	-85.1	-91.4	-32.2	-31.7	-65.1	-42.9
8	9.6	9668.6		-9.6	-10.3	-84.2	-70.7	-13.2	-6.8	-52.9	-40.4
7	9.5	9678.1		-9.6	-10.5	-84.2	-70.7	-13.2	-6.8	-52.9	-40.4
4	19.4	19.4	Tr.4	-23.0	-74.1	-97.7	-99.2	-29.2	-59.7	-90.5	-84.4
3	21.5	41.0	Tr.4	-20.6	-43.3	-95.4	-95.3	-18.2	-18.7	-41.6	-42.8
23	1332.0	1373.0	Tr.4	-44.9	-78.9	-95.9	-96.4	-8.3	-10.4	-31.3	-39.1
2	8.6	1381.5	Tr.4	-44.4	-17.3	-95.9	-96.7	-10.2	-12.1	-32.6	-39.9
5	1957.6	1957.6	Tr.5	-6.4	-85.4	-98.2	-98.4	-10.1	-8.8	-77.4	-71.2
6	67.1	67.1	Tr.6	-4.3	-63.5	-24.9	-32.0	-12.3	-18.7	-19.0	-24.7
1	1060.9	14145.2		-8.1	-24.8	-89.4	-80.1	-12.3	-7.1	-60.6	-48.6

Appendix 3. SWAPP estimated annual average cumulative flow and sediment and nutrient losses at the outlet of each sub-basin for the Whelp Creek Sub-watershed.

Table A3.1. Whelp Creek sub-basin scale environmental results for Scenario 1 (baseline).

	Drainage area			Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets							
Sub-basin	Individual	Cumulative	Tributary (Tr.)	Flow ($m^3 s^{-1}$)	TSS (Mg)	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------					---------- (kg) ----------					
1	79.7	79.7		0.000	0.056	4.9	1.1	1.3	4.7	6.2	5.8
2	35.6	35.6	Tr.1	0.000	0.000	0.0	0.0	0.3	6.2	0.3	6.2
3	28.4	143.6		0.001	0.063	8.6	1.5	2.1	11.9	10.7	13.4
4	41.8	41.8	Tr.2	0.000	0.091	2.2	0.3	0.7	10.4	3.0	10.7
7	373.6	415.4	Tr.2	0.002	0.564	13.1	1.8	9.7	29.1	22.8	30.8
5	14.8	430.2	Tr.2	0.000	0.012	11.0	0.2	0.0	5.5	11.0	5.7
6	8.1	438.2	Tr.2	0.002	0.589	29.3	2.1	9.8	39.7	39.1	41.8
18	1568.6	2150.5		0.012	21.340	288.8	110.2	109.3	232.7	398.1	342.9
17	23.6	2174.1		0.012	3.225	280.7	99.9	97.9	258.7	378.6	358.6
9	231.5	231.5	Tr.3	0.001	0.099	161.8	12.8	8.9	19.7	170.7	32.5
8	10.2	10.2	Tr.3-1	0.000	0.069	0.1	0.1	0.1	0.0	0.2	0.1
10	47.7	289.4	Tr.3	0.001	0.433	135.7	11.6	10.4	24.2	146.1	35.7
11	65.2	65.2	Tr.3-2	0.000	0.004	0.0	0.0	0.0	0.2	0.0	0.2
12	31.5	96.7	Tr.3-2	0.000	0.008	0.0	0.0	0.9	1.0	0.9	1.0
16	366.1	752.2	Tr.3	0.003	2.021	147.5	17.5	44.6	57.3	192.1	74.8
13	3.7	3.7	Tr.3-3	0.000	0.003	0.0	0.2	0.0	0.0	0.0	0.2
14	995.8	999.5	Tr.3-3	0.006	11.788	332.9	191.7	68.0	270.4	401.0	462.2
15	30.6	1030.1	Tr.3-3	0.006	0.300	117.5	67.4	23.1	87.4	140.6	154.8
22	164.9	1947.2	Tr.3	0.011	4.933	346.6	111.3	97.4	153.8	444.0	265.1
19	25.9	25.9	Tr.4	0.001	0.497	2.0	2.0	3.7	9.7	5.7	11.6
20	24.4	4147.3		0.024	9.927	645.0	243.5	208.0	439.3	853.0	682.8

Table A3.2. Whelp Creek sub-basin scale environmental results for Scenario 1 (baseline).

	Drainage area			Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets							
Sub-basin	Individual	Cumulative	Tributary (Tr.)	Flow (mm)	TSS (Mg ha^{-1})	ON	OP	NO_3-N	PO_4-P	TN	TP
	(ha)	(ha)				(kg ha^{-1})					
1	79.7	79.7		14	0.001	0.06	0.01	0.02	0.06	0.08	0.07
2	35.6	35.6	Tr.1	18	0.000	0.00	0.00	0.01	0.17	0.01	0.17
3	28.4	143.6		16	0.000	0.06	0.01	0.01	0.08	0.07	0.09
4	41.8	41.8	Tr.2	19	0.002	0.05	0.01	0.02	0.25	0.07	0.26
7	373.6	415.4	Tr.2	14	0.001	0.03	0.00	0.02	0.07	0.05	0.07
5	14.8	430.2	Tr.2	0.5	0.000	0.03	0.00	0.00	0.01	0.03	0.01
6	8.1	438.2	Tr.2	14	0.001	0.07	0.00	0.02	0.09	0.09	0.10
18	1568.6	2150.5		18	0.010	0.13	0.05	0.05	0.11	0.19	0.16
17	23.6	2174.1		18	0.001	0.13	0.05	0.05	0.12	0.17	0.16
9	231.5	231.5	Tr.3	10	0.000	0.70	0.06	0.04	0.08	0.74	0.14
8	10.2	10.2	Tr.3-1	55	0.007	0.01	0.01	0.01	0.00	0.02	0.01
10	47.7	289.4	Tr.3	11	0.001	0.47	0.04	0.04	0.08	0.50	0.12
11	65.2	65.2	Tr.3-2	2	0.000	0.00	0.00	0.00	0.00	0.00	0.00
12	31.5	96.7	Tr.3-2	4	0.000	0.00	0.00	0.01	0.01	0.01	0.01
16	366.1	752.2	Tr.3	12	0.003	0.20	0.02	0.06	0.08	0.26	0.10
13	3.7	3.7	Tr.3-3	32	0.001	0.00	0.05	0.00	0.01	0.00	0.06
14	995.8	999.5	Tr.3-3	20	0.012	0.33	0.19	0.07	0.27	0.40	0.46
15	30.6	1030.1	Tr.3-3	19	0.000	0.11	0.07	0.02	0.08	0.14	0.15
22	164.9	1947.2	Tr.3	18	0.003	0.18	0.06	0.05	0.08	0.23	0.14
19	25.9	25.9	Tr.4	80	0.019	0.08	0.08	0.14	0.37	0.22	0.45
20	24.4	4147.3		18	0.002	0.16	0.06	0.05	0.11	0.21	0.16

Table A3.3. Predicted baseline 30-yr averages for flow, total suspended solids (TSS), and fractions of nitrogen and phosphorus for the beneficial management practices (BMP) sites in Whelp Creek Sub-watershed.

BMP site	Subarea ID	Subarea size (ha)	Sub-basin ID	Flow (mm)	TSS ($Mg\ ha^{-1}$)	TN	TP	ON	OP	NO_3^-N	PO_4-P
						($kg\ ha^{-1}$)					
EFD	1297	0.5	5	27.3	0.00	4.14	1.25	4.11	0.08	0.03	1.17
EFD	1311	2.5	5	24.9	0.00	3.46	1.35	3.45	0.06	0.01	1.29
EFD	5000	3.1	5	25.0	0.00	3.18	1.68	3.17	0.05	0.01	1.63
NFD	415	1.1	1	16.2	0.00	0.16	0.17	0.11	0.05	0.05	0.12
NFD	424	0.6	1	16.0	0.00	0.16	0.17	0.11	0.05	0.05	0.12
NFD	432	0.7	3	34.7	0.00	0.14	0.11	0.06	0.02	0.08	0.09
NFD	604	3.1	3	16.6	0.00	0.18	0.08	0.14	0.02	0.04	0.06
NFD	419	1.1	2	24.5	0.01	0.62	0.31	0.56	0.04	0.06	0.27
NPS	934	0.4	17	7.8	0.00	0.31	0.16	0.21	0.14	0.10	0.02
NPS	940	3.2	17	21.9	0.00	0.93	1.58	0.82	0.17	0.11	1.41
NPS	2400	0.04	17	5.3	0.00	0.06	0.01	0.00	0.00	0.06	0.01
NPS	748	1.2	17	24.4	0.00	1.11	1.59	1.05	0.15	0.06	1.44
NPS	927	0.2	17	22.5	0.00	0.88	1.53	0.82	0.16	0.06	1.37
NPS	2401	0.8	17	4.6	0.00	0.01	0.01	0.00	0.00	0.01	0.01
SFD	5500	0.8	10	11.3	0.01	0.27	0.20	0.22	0.03	0.05	0.17
SFD	5501	0.2	10	11.3	0.01	0.27	0.20	0.22	0.03	0.05	0.17
SFD	1918	18.5	10	13.0	0.00	0.07	0.14	0.02	0.01	0.05	0.13
SFD	1909	26.0	10	11.1	0.00	0.28	0.20	0.23	0.03	0.05	0.17
SPS	2717	3.7	13	32.6	0.00	5.93	1.66	5.90	1.47	0.03	0.19
SPS	2719	9.9	14	28.2	0.00	1.06	1.73	0.90	0.78	0.16	0.95
SPS	6000	10.7	14	65.7	0.00	2.93	5.16	2.44	2.23	0.49	2.93
SPS	6001	11.5	14	65.9	0.00	2.94	5.45	2.45	2.52	0.49	2.93
WFD	5101	2.0	4	18.5	0.00	0.10	0.29	0.07	0.01	0.03	0.28
WFD	1988	16.5	4	17.7	0.00	0.04	0.27	0.01	0.00	0.03	0.27
WFD	5100	5.1	4	17.9	0.00	0.05	0.27	0.02	0.00	0.03	0.27
WFD	1684	0.8	4	22.0	0.00	0.39	0.22	0.37	0.08	0.02	0.14
WFD	1694	9.8	4	22.2	0.00	1.07	0.44	1.04	0.20	0.03	0.24

Table A3.4. Whelp Creek sub-basin scale environmental results for Scenario 2 (field study BMPs): Flow and sediment and nutrient losses.

Sub-basin	Drainage area: Individual	Drainage area: Cumulative	Tributary (Tr.)	Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets: Flow ($m^3 s^{-1}$)	TSS (Mg)	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------					-------------------------------- (kg)					--------------------------------
1	79.7	79.7		0.000	0.056	4.7	1.1	1.3	4.4	6.0	5.5
2	35.6	35.6	Tr.1	0.000	0.000	0.0	0.0	0.3	6.2	0.3	6.2
3	28.4	143.6		0.001	0.063	7.7	1.4	2.1	11.6	9.8	13.0
4	41.8	41.8	Tr.2	0.000	0.091	2.2	0.3	0.7	10.4	3.0	10.7
7	373.6	415.4	Tr.2	0.002	0.564	13.1	1.8	9.7	29.1	22.8	30.8
5	14.8	430.2	Tr.2	0.000	0.012	5.1	0.1	0.0	3.0	5.1	3.1
6	8.1	438.2	Tr.2	0.002	0.589	23.5	2.0	9.8	37.3	33.2	39.3
18	1568.6	2150.5		0.012	21.344	282.1	110.1	109.3	229.9	391.3	340.0
17	23.6	2174.1		0.012	3.226	271.3	99.2	97.7	251.7	369.0	350.9
9	231.5	231.5	Tr.3	0.001	0.099	161.8	12.8	8.9	19.7	170.7	32.5
8	10.2	10.2	Tr.3-1	0.000	0.069	0.1	0.1	0.1	0.0	0.2	0.1
10	47.7	289.4	Tr.3	0.001	0.335	135.6	11.5	10.4	23.9	146.0	35.4
11	65.2	65.2	Tr.3-2	0.000	0.004	0.0	0.0	0.0	0.2	0.0	0.2
12	31.5	96.7	Tr.3-2	0.000	0.008	0.0	0.0	0.9	1.0	0.9	1.0
16	366.1	752.2	Tr.3	0.003	1.924	147.5	17.5	44.7	57.0	192.1	74.5
13	3.7	3.7	Tr.3-3	0.000	0.003	0.0	0.2	0.0	0.0	0.0	0.2
14	995.8	999.5	Tr.3-3	0.006	11.695	309.3	136.3	47.8	222.7	357.2	358.9
15	30.6	1030.1	Tr.3-3	0.006	0.299	108.5	46.4	16.3	71.0	124.8	117.5
22	164.9	1947.2	Tr.3	0.011	4.843	337.6	90.4	90.7	137.3	428.3	227.6
19	25.9	25.9	Tr.4	0.001	0.497	2.0	2.0	3.7	9.7	5.7	11.6
20	24.4	4147.3		0.024	9.839	626.6	221.9	201.1	415.7	827.7	637.7

Table A 3.5. Whelp Creek sub-basin scale environmental results for Scenario 2 (field study BMPs): Percent change relative to the baseline.

Sub-basin	Drainage area: Individual	Drainage area: Cumulative	Tributary (Tr.)	Changes of flow and sediment and nutrient losses from baseline scenario at the sub-basin outlets: Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			(%)							
1	79.7	79.7		0.7	-0.1	-4.7	-1.2	0.6	-6.0	-3.6	-5.1
2	35.6	35.6	Tr.1	0.0	0.0			0.0	0.0	0.0	0.0
3	28.4	143.6		0.5	0.0	-10.7	-4.3	0.7	-3.0	-8.5	-3.1
4	41.8	41.8	Tr.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	373.6	415.4	Tr.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	14.8	430.2	Tr.2	1.3	2.0	-53.6	-53.4	-3.9	-44.5	-53.5	-44.8
6	8.1	438.2	Tr.2	0.0	0.0	-20.0	-4.2	0.0	-6.1	-15.0	-6.0
18	1568.6	2150.5		0.0	0.0	-2.3	-0.1	0.0	-1.2	-1.7	-0.9
17	23.6	2174.1		0.0	0.0	-3.4	-0.7	-0.2	-2.7	-2.5	-2.2
9	231.5	231.5	Tr.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	10.2	10.2	Tr.3-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	47.7	289.4	Tr.3	0.3	-22.6	0.0	-0.3	0.0	-1.3	0.0	-1.0
11	65.2	65.2	Tr.3-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	31.5	96.7	Tr.3-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	366.1	752.2	Tr.3	0.1	-4.8	0.0	-0.1	0.0	-0.5	0.0	-0.4
13	3.7	3.7	Tr.3-3	-5.2	-3.9	15.9	-6.2	-15.4	-3.5	15.8	-5.7
14	995.8	999.5	Tr.3-3	-0.4	-0.8	-7.1	-28.9	-29.7	-17.7	-10.9	-22.3
15	30.6	1030.1	Tr.3-3	-0.4	-0.3	-7.7	-31.1	-29.3	-18.7	-11.2	-24.1
22	164.9	1947.2	Tr.3	-0.2	-1.8	-2.6	-18.8	-6.9	-10.8	-3.5	-14.1
19	25.9	25.9	Tr.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	24.4	4147.3		-0.1	-0.9	-2.9	-8.9	-3.3	-5.4	-3.0	-6.6

Table A3.6. Predicted Scenario 2 30 -yr averages for flow, total suspended solids (TSS), and fractions of nitr ogen and phosphorus for the beneficial management practices (BMP) sites in Whelp Creek Sub -watershed.

BMP Site	Subarea ID	Subarea Size (ha)	Sub-basin ID	Flow (mm)	TSS ($Mg\ ha^{-1}$)	TN	TP	ON	OP	NO_3^-N	PO_4-P
						($kg\ ha^{-1}$)					
EFD	1297	0.5	5	27.6	0.00	0.03	0.11	0.00	0.00	0.03	0.11
EFD	1311	2.5	5	25.2	0.00	1.69	0.79	1.68	0.03	0.01	0.76
EFD	5000	3.1	5	25.1	0.00	2.80	1.50	2.79	0.05	0.01	1.45
NFD	415	1.1	1	16.2	0.00	0.16	0.17	0.11	0.05	0.05	0.12
NFD	424	0.6	1	16.0	0.00	0.16	0.16	0.11	0.05	0.05	0.11
NFD	432	0.7	3	34.9	0.00	0.09	0.10	0.01	0.02	0.08	0.08
NFD	604	3.1	3	16.7	0.00	0.15	0.07	0.11	0.01	0.04	0.06
NFD	419	1.1	2	24.5	0.01	0.62	0.31	0.56	0.04	0.06	0.27
NPS	934	0.4	17	7.2	0.00	0.09	0.08	0.02	0.07	0.07	0.01
NPS	940	3.2	17	19.9	0.00	0.73	1.35	0.64	0.13	0.09	1.22
NPS	2400	0.04	17	5.6	0.00	0.01	0.01	0.00	0.00	0.01	0.01
NPS	748	1.2	17	20.7	0.00	0.79	1.20	0.74	0.10	0.05	1.10
NPS	927	0.2	17	19.7	0.00	0.65	1.25	0.60	0.11	0.05	1.14
NPS	2401	0.8	17	5.0	0.00	0.01	0.01	0.00	0.00	0.01	0.01
SFD	5500	0.8	10	11.5	0.01	0.27	0.20	0.22	0.03	0.05	0.17
SFD	5501	0.2	10	11.7	0.00	0.27	0.20	0.22	0.03	0.05	0.17
SFD	1918	18.5	10	12.9	0.00	0.07	0.14	0.02	0.01	0.05	0.13
SFD	1909	26.0	10	11.0	0.00	0.28	0.20	0.23	0.03	0.05	0.17
SPS	2717	3.7	13	33.4	0.00	5.95	1.60	5.89	1.41	0.06	0.19
SPS	2719	9.9	14	24.4	0.00	0.93	1.28	0.83	0.59	0.10	0.69
SPS	6000	10.7	14	53.5	0.00	2.49	3.75	2.21	1.62	0.28	2.13
SPS	6001	11.5	14	53.3	0.00	2.54	3.95	2.27	1.85	0.27	2.10
WFD	5101	2.0	4	18.5	0.00	0.10	0.29	0.07	0.01	0.03	0.28
WFD	1988	16.5	4	17.7	0.00	0.04	0.27	0.01	0.00	0.03	0.27
WFD	5100	5.1	4	17.9	0.00	0.05	0.27	0.02	0.00	0.03	0.27
WFD	1684	0.8	4	22.0	0.00	0.39	0.22	0.37	0.08	0.02	0.14
WFD	1694	9.8	4	22.2	0.00	1.07	0.44	1.04	0.20	0.03	0.24

Table A3.7. Whelp Creek sub-basin scale environmental results for Scenario 3 (AOPA): Flow and sediment and nutrient losses.

Sub-basin	Drainage area: Individual	Drainage area: Cumulative	Tributary (Tr.)	Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets: Flow ($m^3 s^{-1}$)	TSS (Mg)	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------					---------------- (kg) ----------------					
1	79.7	79.7		0.000	0.056	4.3	0.8	1.2	3.4	5.5	4.2
2	35.6	35.6	Tr.1	0.000	0.000	0.0	0.0	0.3	4.4	0.3	4.4
3	28.4	143.6		0.001	0.063	7.1	0.9	2.0	8.7	9.1	9.6
4	41.8	41.8	Tr.2	0.000	0.093	1.9	0.1	0.7	8.9	2.6	9.1
7	373.6	415.4	Tr.2	0.002	0.568	12.3	1.4	9.7	26.5	22.0	27.9
5	14.8	430.2	Tr.2	0.000	0.012	10.3	0.1	0.0	2.7	10.3	2.8
6	8.1	438.2	Tr.2	0.002	0.593	25.2	1.5	9.7	32.0	34.9	33.5
18	1568.6	2150.5		0.012	21.555	252.7	90.9	119.9	202.3	372.6	293.2
17	23.6	2174.1		0.012	3.258	241.3	79.0	107.3	230.4	348.6	309.4
9	231.5	231.5	Tr.3	0.001	0.111	139.9	6.7	9.7	20.2	149.6	26.9
8	10.2	10.2	Tr.3-1	0.000	0.069	0.1	0.1	0.1	0.0	0.2	0.1
10	47.7	289.4	Tr.3	0.001	0.443	119.4	6.2	11.0	22.8	130.4	29.1
11	65.2	65.2	Tr.3-2	0.000	0.004	0.0	0.0	0.0	0.2	0.0	0.2
12	31.5	96.7	Tr.3-2	0.000	0.008	0.0	0.0	0.9	0.6	0.9	0.6
16	366.1	752.2	Tr.3	0.003	2.012	124.6	8.7	40.1	49.8	164.7	58.4
13	3.7	3.7	Tr.3-3	0.000	0.003	0.0	0.2	0.0	0.0	0.0	0.2
14	995.8	999.5	Tr.3-3	0.006	11.854	304.6	140.6	54.7	225.3	359.2	365.9
15	30.6	1030.1	Tr.3-3	0.006	0.302	107.1	48.1	18.9	72.5	126.0	120.6
22	164.9	1947.2	Tr.3	0.011	4.935	312.9	83.1	88.8	131.4	401.7	214.5
19	25.9	25.9	Tr.4	0.001	0.501	0.6	0.9	3.7	8.9	4.3	9.8
20	24.4	4147.3		0.024	9.969	570.2	193.1	208.8	387.7	779.0	580.9

Table A3.8. Whelp Creek sub-basin scale environmental results for Scenario 3 (AOPA): Percent change relative to the baseline.

Sub-basin	Drainage area: Individual	Drainage area: Cumulative	Tributary (Tr.)	Changes of flow and sediment and nutrient losses from baseline scenario at the sub-basin outlets: Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			---------- (%) ----------							
1	79.7	79.7		0.2	0.5	-12.6	-28.7	-6.0	-26.9	-11.2	-27.2
2	35.6	35.6	Tr.1	1.3	-2.0			-1.6	-28.8	-1.6	-28.8
3	28.4	143.6		0.8	0.4	-17.7	-39.4	-4.0	-26.9	-15.1	-28.2
4	41.8	41.8	Tr.2	3.9	3.0	-12.3	-57.7	-8.1	-14.1	-11.2	-15.3
7	373.6	415.4	Tr.2	0.8	0.7	-6.1	-20.8	-0.2	-8.9	-3.6	-9.6
5	14.8	430.2	Tr.2	0.2	0.4	-6.5	-38.0	2.8	-50.3	-6.5	-50.0
6	8.1	438.2	Tr.2	0.7	0.7	-14.1	-27.6	-0.5	-19.4	-10.7	-19.8
18	1568.6	2150.5		0.6	1.0	-12.5	-17.6	9.8	-13.1	-6.4	-14.5
17	23.6	2174.1		0.7	1.0	-14.0	-20.9	9.6	-11.0	-7.9	-13.7
9	231.5	231.5	Tr.3	9.3	12.7	-13.5	-48.1	8.7	2.8	-12.4	-17.3
8	10.2	10.2	Tr.3-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	47.7	289.4	Tr.3	6.6	2.3	-12.0	-46.1	5.6	-5.5	-10.7	-18.7
11	65.2	65.2	Tr.3-2	0.0	0.0	0.0	-34.5	0.1	-12.3	0.1	-12.4
12	31.5	96.7	Tr.3-2	-2.0	-2.4	-10.4	-29.1	-2.0	-36.1	-2.0	-36.1
16	366.1	752.2	Tr.3	1.5	-0.5	-15.6	-50.5	-10.1	-13.1	-14.3	-21.9
13	3.7	3.7	Tr.3-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	995.8	999.5	Tr.3-3	0.4	0.6	-8.5	-26.7	-19.6	-16.7	-10.4	-20.8
15	30.6	1030.1	Tr.3-3	0.4	0.6	-8.8	-28.7	-18.1	-17.0	-10.4	-22.1
22	164.9	1947.2	Tr.3	0.6	0.1	-9.7	-25.3	-8.8	-14.6	-9.5	-19.1
19	25.9	25.9	Tr.4	0.7	0.7	-72.6	-56.7	0.2	-7.8	-25.7	-16.1
20	24.4	4147.3		0.7	0.4	-11.6	-20.7	0.4	-11.7	-8.7	-14.9

Table A3.9. Whelp Creek sub-basin scale environmental results for Scenario 4: Flow and sediment and nutrient losses.

Sub-basin	Drainage area: Individual	Drainage area: Cumulative	Tributary (Tr.)	Flow ($m^3 s^{-1}$)	TSS (Mg)	ON	OP	NO_3-N	PO_4-P	TN	TP
	(ha)	(ha)		Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets		(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
1	79.7	79.7		0.000	0.057	4.2	0.7	1.3	3.3	5.6	4.0
2	35.6	35.6	Tr.1	0.000	0.000	0.0	0.0	0.3	4.0	0.3	4.0
3	28.4	143.6		0.001	0.064	6.6	0.8	2.0	8.1	8.6	8.9
4	41.8	41.8	Tr.2	0.000	0.088	2.1	0.0	0.6	3.8	2.7	3.8
7	373.6	415.4	Tr.2	0.002	0.560	12.6	1.3	9.6	22.3	22.2	23.6
5	14.8	430.2	Tr.2	0.000	0.012	10.3	0.1	0.0	2.7	10.4	2.8
6	8.1	438.2	Tr.2	0.002	0.585	25.4	1.4	9.6	27.6	35.0	29.1
18	1568.6	2150.5		0.012	21.607	252.5	88.0	115.7	201.7	368.2	289.7
17	23.6	2174.1		0.012	3.263	241.1	76.2	102.8	229.6	343.9	305.8
9	231.5	231.5	Tr.3	0.001	0.114	80.3	4.3	9.8	22.2	90.1	26.5
8	10.2	10.2	Tr.3-1	0.000	0.069	0.1	0.1	0.1	0.0	0.2	0.1
10	47.7	289.4	Tr.3	0.001	0.447	70.7	4.2	11.0	24.4	81.7	28.6
11	65.2	65.2	Tr.3-2	0.000	0.004	0.0	0.0	0.0	0.2	0.0	0.2
12	31.5	96.7	Tr.3-2	0.000	0.008	0.0	0.0	0.9	0.6	0.9	0.6
16	366.1	752.2	Tr.3	0.003	2.018	76.2	6.7	40.6	51.3	116.8	57.9
13	3.7	3.7	Tr.3-3	0.000	0.003	0.0	0.2	0.0	0.0	0.0	0.2
14	995.8	999.5	Tr.3-3	0.006	11.826	300.5	134.3	54.8	230.0	355.3	364.3
15	30.6	1030.1	Tr.3-3	0.006	0.301	105.4	45.8	19.0	74.0	124.5	119.8
22	164.9	1947.2	Tr.3	0.011	4.937	262.9	78.8	89.4	134.4	352.3	213.2
19	25.9	25.9	Tr.4	0.001	0.501	0.6	0.8	3.7	8.9	4.3	9.8
20	24.4	4147.3		0.024	9.975	520.1	186.1	204.9	389.9	725.0	576.0

Table A3.10. Whelp Creek sub-basin scale environmental results for Scenario 4: Percent change relative to the baseline.

	Drainage area			Changes of flow and sediment and nutrient losses from baseline scenario at the sub-basin outlets							
Sub-basin	Individual	Cumulative	Tributary (Tr.)	Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			---------- (%) ----------							
1	79.7	79.7		-0.6	2.6	-13.7	-32.9	-0.7	-29.9	-10.9	-30.5
2	35.6	35.6	Tr.1	-4.3	-6.9			-12.8	-34.7	-12.8	-34.7
3	28.4	143.6		-1.8	2.0	-23.5	-44.4	-3.2	-32.4	-19.6	-33.7
4	41.8	41.8	Tr.2	-1.3	-2.7	-5.7	-89.3	-24.7	-63.8	-10.5	-64.6
7	373.6	415.4	Tr.2	0.1	-0.6	-3.9	-24.3	-1.2	-23.3	-2.7	-23.3
5	14.8	430.2	Tr.2	0.2	0.4	-6.2	-47.0	2.9	-50.3	-6.2	-50.2
6	8.1	438.2	Tr.2	-0.2	-0.7	-13.5	-31.9	-1.6	-30.4	-10.5	-30.5
18	1568.6	2150.5		0.4	1.3	-12.6	-20.2	5.9	-13.3	-7.5	-15.5
17	23.6	2174.1		0.5	1.2	-14.1	-23.7	5.0	-11.3	-9.2	-14.7
9	231.5	231.5	Tr.3	10.8	15.3	-50.4	-66.5	9.5	13.1	-47.2	-18.4
8	10.2	10.2	Tr.3-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	47.7	289.4	Tr.3	7.6	3.2	-47.9	-63.4	6.2	0.9	-44.1	-19.9
11	65.2	65.2	Tr.3-2	0.0	0.0	0.0	-34.5	0.1	-12.3	0.1	-12.4
12	31.5	96.7	Tr.3-2	-2.2	-2.6	-10.4	-29.0	-2.1	-34.5	-2.1	-34.5
16	366.1	752.2	Tr.3	1.9	-0.2	-48.4	-62.0	-9.0	-10.5	-39.2	-22.5
13	3.7	3.7	Tr.3-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	995.8	999.5	Tr.3-3	0.2	0.3	-9.7	-30.0	-19.4	-15.0	-11.4	-21.2
15	30.6	1030.1	Tr.3-3	0.3	0.3	-10.3	-32.1	-17.6	-15.4	-11.5	-22.6
22	164.9	1947.2	Tr.3	0.6	0.1	-24.2	-29.2	-8.2	-12.6	-20.7	-19.6
19	25.9	25.9	Tr.4	0.7	0.7	-73.0	-57.0	0.2	-7.8	-25.8	-16.1
20	24.4	4147.3		0.5	0.5	-19.4	-23.6	-1.5	-11.2	-15.0	-15.7

Table A3.11. Whelp Creek sub-basin scale environmental results for Scenario 5: Flow and sediment and nutrient losses.

	Drainage area			Annual average cumulative flow and sediment and nutrient losses at the sub-basin outlets							
Sub-basin	Individual	Cumulative	Tributary (Tr.)	Flow ($m^3 s^{-1}$)	TSS (Mg)	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------					------ (kg) ------					
1	79.7	79.7		0.000	0.026	0.3	0.1	0.3	0.6	0.5	0.7
2	35.6	35.6	Tr.1	0.000	0.000	0.0	0.0	0.2	4.0	0.2	4.0
3	28.4	143.6		0.000	0.030	2.0	0.2	0.9	5.2	2.9	5.4
4	41.8	41.8	Tr.2	0.000	0.085	2.2	0.0	0.7	4.5	2.9	4.5
7	373.6	415.4	Tr.2	0.001	0.469	7.1	0.7	5.1	12.3	12.2	13.0
5	14.8	430.2	Tr.2	0.000	0.012	10.2	0.1	0.0	2.7	10.2	2.8
6	8.1	438.2	Tr.2	0.001	0.486	17.4	0.8	5.1	17.0	22.5	17.8
18	1568.6	2150.5		0.007	10.509	200.7	63.3	70.6	122.0	271.3	185.3
17	23.6	2174.1		0.007	1.706	176.1	50.4	58.1	138.3	234.2	188.7
9	231.5	231.5	Tr.3	0.000	0.149	11.3	0.7	3.4	8.4	14.6	9.1
8	10.2	10.2	Tr.3-1	0.000	0.068	0.1	0.1	0.1	0.0	0.2	0.1
10	47.7	289.4	Tr.3	0.001	0.387	13.2	0.9	5.0	13.1	18.3	14.1
11	65.2	65.2	Tr.3-2	0.000	0.003	0.0	0.0	0.0	0.1	0.0	0.1
12	31.5	96.7	Tr.3-2	0.000	0.008	0.0	0.0	0.8	0.5	0.9	0.5
16	366.1	752.2	Tr.3	0.002	0.947	19.3	3.9	20.9	24.2	40.2	28.1
13	3.7	3.7	Tr.3-3	0.000	0.003	0.0	0.2	0.0	0.0	0.0	0.2
14	995.8	999.5	Tr.3-3	0.001	0.583	14.4	5.2	8.1	2.9	22.5	8.1
15	30.6	1030.1	Tr.3-3	0.001	0.044	1.0	0.3	0.7	0.2	1.7	0.4
22	164.9	1947.2	Tr.3	0.005	2.174	97.8	28.0	48.2	32.3	146.1	60.2
19	25.9	25.9	Tr.4	0.001	0.499	0.4	0.6	3.7	8.9	4.1	9.5
20	24.4	4147.3		0.013	5.417	287.6	106.1	117.7	195.1	405.3	301.2

Table A3.12. Whelp Creek sub-basin scale environmental results for Scenario 5: Percent change relative to the baseline.

Sub-basin	Drainage area Individual	Drainage area Cumulative	Tributary (Tr.)	Changes of flow and sediment and nutrient losses from baseline scenario at the sub-basin outlets Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			----------	----------	----------	----------	(%)	----------	----------	----------
1	79.7	79.7		-75.2	-53.7	-94.5	-91.5	-79.3	-88.0	-91.3	-88.7
2	35.6	35.6	Tr.1	-6.1	-7.0	0.0	0.0	-21.3	-35.3	-21.3	-35.3
3	28.4	143.6		-43.4	-52.1	-77.0	-88.7	-57.9	-56.2	-73.3	-59.8
4	41.8	41.8	Tr.2	-4.1	-6.1	-2.3	-93.3	-7.7	-56.8	-3.7	-57.8
7	373.6	415.4	Tr.2	-49.9	-16.8	-45.7	-59.8	-47.6	-57.6	-46.5	-57.8
5	14.8	430.2	Tr.2	0.2	0.4	-7.9	-47.2	3.2	-50.0	-7.9	-49.9
6	8.1	438.2	Tr.2	-48.1	-17.4	-40.6	-62.7	-47.7	-57.2	-42.4	-57.4
18	1568.6	2150.5		-43.7	-50.8	-30.5	-42.6	-35.4	-47.6	-31.9	-46.0
17	23.6	2174.1		-43.6	-47.1	-37.3	-49.6	-40.6	-46.6	-38.1	-47.4
9	231.5	231.5	Tr.3	-34.9	50.7	-93.0	-94.8	-61.9	-57.1	-91.4	-72.0
8	10.2	10.2	Tr.3-1	-1.7	-0.8	0.0	0.0	0.0	0.0	0.0	0.0
10	47.7	289.4	Tr.3	-27.4	-10.6	-90.2	-91.8	-51.7	-45.7	-87.5	-60.6
11	65.2	65.2	Tr.3-2	-12.4	-8.7	0.8	-35.4	56.8	-66.3	38.3	-66.0
12	31.5	96.7	Tr.3-2	-12.1	-7.6	-10.7	-30.2	-6.0	-51.0	-6.0	-50.9
16	366.1	752.2	Tr.3	-36.5	-53.2	-86.9	-77.7	-53.2	-57.7	-79.1	-62.4
13	3.7	3.7	Tr.3-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	995.8	999.5	Tr.3-3	-76.8	-95.1	-95.7	-97.3	-88.1	-98.9	-94.4	-98.2
15	30.6	1030.1	Tr.3-3	-80.4	-85.5	-99.1	-99.6	-97.0	-99.8	-98.8	-99.7
22	164.9	1947.2	Tr.3	-56.2	-55.9	-71.8	-74.9	-50.5	-79.0	-67.1	-77.3
19	25.9	25.9	Tr.4	-0.6	0.5	-80.2	-70.2	0.4	-7.8	-28.2	-18.3
20	24.4	4147.3		-47.4	-45.4	-55.4	-56.4	-43.4	-55.6	-52.5	-55.9

Appendix 4. SWAPP estimated annual average cumulative flow and sediment and nutrient losses at the outlet of each sub-basin for Lower Little Bow River Field (LLB) under different scenario input data.

Table A 4.1. Lower Little Bow River Field annual average cumulative flow, sediment, and nutrient values at the outlet of each sub-basin under different scenario.

Scenario[z]	Sub-basin ID	Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
		($m^3\ s^{-1}$)	(Mg)	(kg)					
Scenario 1	1	0.0006	1.057	2.24	1.21	101.34	33.44	103.59	34.66
Scenario 1	2	0.0002	0.002	0.15	0.13	30.31	10.73	30.46	10.86
Scenario 2	1	0.0005	0.942	1.89	0.76	13.25	14.63	15.14	15.39
Scenario 2	2	0.0002	0.002	0.08	0.03	4.34	4.89	4.41	4.92
Scenario 3	1	0.0006	1.059	2.18	1.11	95.73	31.42	97.90	32.53
Scenario 3	2	0.0002	0.003	0.09	0.05	27.32	10.00	27.41	10.05
Scenario 4	1	0.0006	1.024	2.15	0.81	71.99	14.76	74.15	15.57
Scenario 4	2	0.0002	0.002	0.09	0.03	20.44	4.64	20.52	4.67
Scenario 5	1	0.0005	0.919	1.16	0.42	64.03	14.69	65.19	15.11
Scenario 5	2	0.0002	0.002	0.08	0.03	7.78	4.87	7.86	4.90
		(mm)	($Mg\ ha^{-1}$)	($kg\ ha^{-1}$)					
Scenario 1	1	22.2	0.013	0.03	0.01	1.22	0.40	1.25	0.42
Scenario 1	2	22.3	0.000	0.005	0.00	0.97	0.34	0.97	0.35
Scenario 2	1	20.4	0.011	0.02	0.01	0.16	0.18	0.18	0.19
Scenario 2	2	21.4	0.000	0.00	0.00	0.14	0.16	0.14	0.16
Scenario 3	1	22.3	0.013	0.03	0.01	1.16	0.38	1.18	0.39
Scenario 3	2	22.3	0.000	0.00	0.00	0.87	0.32	0.87	0.32
Scenario 4	1	22.2	0.012	0.03	0.01	0.87	0.18	0.90	0.19
Scenario 4	2	23.6	0.000	0.00	0.00	0.65	0.15	0.65	0.15
Scenario 5	1	17.4	0.011	0.01	0.01	0.77	0.18	0.79	0.18
Scenario 5	2	18.9	0.000	0.00	0.00	0.25	0.16	0.25	0.16

[z] Scenario 1 = baseline; Scenario 2 = field study BMPs; Scenario 3 = AOPA management practices; Scenarios 4 and 5 = alternative scenarios.

Table A 4.2. Lower Little Bow River Field site changes of flow, sediment, and nutrients at the outlet of each sub-basin under different scenario.

Scenario[z]	Sub-basin ID	Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
		(%)							
Baseline	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Baseline	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BMP	1	-8.1	-10.9	-15.6	-37.7	-86.9	-56.2	-85.4	-55.6
BMP	2	-3.7	-6.9	-50.0	-74.9	-85.7	-54.5	-85.5	-54.7
AOPA	1	0.2	0.1	-3.0	-8.6	-5.5	-6.0	-5.5	-6.1
AOPA	2	0.2	0.3	-39.1	-58.6	-9.9	-6.8	-10.0	-7.4
Scenario 4	1	-7.1	-7.1	-3.7	-33.3	-29.5	-56.3	-28.4	-55.1
Scenario 4	2	-5.4	-8.3	-42.9	-74.2	-32.2	-56.9	-32.6	-57.0
Scenario 5	1	-21.6	-13.1	-48.3	-65.4	-36.8	-56.1	-37.1	-56.4
Scenario 5	2	-14.9	-3.7	-47.2	-77.2	-74.3	-54.6	-74.2	-54.9

[z] Scenario 1 = baseline; Scenario 2 = field study BMPs; Scenario 3 = AOPA management practices; Scenarios 4 and 5 = alternative scenarios.

Appendix 5. Summary of the economic results for Scenarios 3, 4, and 5.

Table A5.1. Changes in annual net returns for Scenarios 3 (AOPA), 4, and 5 simulated for Indianfarm Creek Watershed relative to Scenario 1 (baseline)

Farm	Farm Size	Scenario 3		Scenario 4		Scenario 5	
	(ha)	Total farm ($ yr^{-1})	($ ha^{-1} yr^{-1})	Total farm ($ yr^{-1})	($ ha^{-1} yr^{-1})	Total farm ($ yr^{-1})	($ ha^{-1} yr^{-1})
Farm1	1,018	1,758	1.73	-4,626	-4.54	-98,582	-96.82
Farm2	357	-5	-0.01	-3,470	-9.72	-3,470	-9.72
Farm3	310	-13	-0.04	-1,053	-3.39	-1,053	-3.39
Farm4	579	-255	-0.44	-5,622	-9.72	187	0.32
Farm5	192	-841	-4.37	-1,834	-9.54	-1,834	-9.54
Farm6	36	0	0.00	-637	-17.48	-7,758	-213.01
Farm7	1,514	-3,171	-2.12	-6,764	-4.47	-141,524	-93.50
Farm8	12,376	-504	-0.04	-789	-0.06	-789	-0.06
Farm9	24	0	0.00	-217	-8.93	6	0.26
Farm10	230	-96	-0.42	-937	-4.08	-937	-4.08
Farm11	268	469	1.75	-183	-0.68	-22,502	-84.12
Farm12	397	-10	-0.02	-607	-1.53	-13,619	-34.34
Farm13	646	0	0.00	-2,801	-4.34	2,259	3.50

Table A5.2. Changes in annual net returns for Scenarios 3 (AOPA), 4, and 5 simulated for Lower Little Bow River Field relative to Scenario 1 (baseline)

Farm	Farm Size	Scenario 3		Scenario 4		Scenario 5	
	(ha)	Total farm ($ yr^{-1})	($ ha^{-1} yr^{-1})	Total farm ($ yr^{-1})	($ ha^{-1} yr^{-1})	Total farm ($ yr^{-1})	($ ha^{-1} yr^{-1})
Farm1	771	-6,271	-8.13	-28,181	-36.55	-30,944	-40.14

Table A5.3. Changes in annual net returns for Scenarios 3 (AOPA), 4, and 5 simulated for Whelp Creek Sub-watershed relative to Scenario 1 (baseline).

Farm	Farm size (ha)	Scenario 3 Total farm ($ yr^{-1})	Scenario 3 ($ ha^{-1} yr^{-1})	Scenario 4 Total farm ($ yr^{-1})	Scenario 4 ($ ha^{-1} yr^{-1})	Scenario 5 Total farm ($ yr^{-1})	Scenario 5 ($ ha^{-1} yr^{-1})
Farm1	28	0	0.00	-4,738	-172.17	-4,808	-174.71
Farm2	59	0	0.00	759	12.94	331	5.63
Farm3	57	-1,935	-34.15	-22,104	-390.12	-22,490	-396.59
Farm4	185	-1,956	-10.60	-29,456	-159.62	-30,210	-163.71
Farm5	63	0	0.00	-127	-2.02	-507	-8.08
Farm6	162	0	0.00	-46	-0.28	-186	-1.15
Farm7	57	0	0.00	24	0.43	67	1.18
Farm8	49	-1,340	-27.59	-6,729	-138.55	-7,156	-147.35
Farm9	292	-9,832	-33.69	-63,509	-217.65	-59,751	-219.45
Farm10	53	0	0.00	11	0.21	6	0.10
Farm11	245	0	0.00	-14,445	-59.01	-15,062	-61.53
Farm12	56	-1,045	-18.64	-3,765	-67.17	-4,107	-73.20
Farm13	251	0	0.00	17	0.07	55	0.11
Farm14	97	0	0.00	-118	-1.22	-82	-0.85
Farm15	111	-56	-0.50	-19,327	-173.66	-20,008	-179.80
Farm16	47	0	0.00	158	3.33	87	1.83
Farm17	83	0	0.00	-122	-1.48	-145	-1.75
Farm18	22	0	0.00	-3,386	-152.10	-3,479	-156.30
Farm19	99	0	0.00	-2	-0.02	-7	-0.07
Farm20	46	0	0.00	9	0.18	17	0.37
Farm21	16	0	0.00	-109	-6.75	-438	-27.07
Farm22	306	-930	-3.04	-349	-1.29	424	2.28
Farm23	52	0	0.00	-10	-0.18	-39	-0.76
Farm24	40	0	0.00	-32	-0.78	-127	-3.13
Farm25	40	0	0.00	-70	-1.73	-282	-6.96
Farm26	109	0	0.00	3	0.03	4	0.03
Farm27	102	-1,283	-12.53	-34,870	-340.56	-35,055	-342.37

Appendix 6. Manure applications simulated for the Indianfarm Creek Watershed.

Table A6.1. Area and manure application rates of nitrogen (N) and phosphorus (P) for the different sub-basins and scenarios simulated for the Indianfarm Creek Watershed.

Sub-basin	Scenario 1[z] Area (ha)	Scenario 1 N --- (kg ha^{-1}) ---	Scenario 1 P	Scenario 2 Area (ha)	Scenario 2 N --- (kg ha^{-1}) ---	Scenario 2 P	Scenario 3 Area (ha)	Scenario 3 N --- (kg ha^{-1}) ---	Scenario 3 P	Scenario 4 Area (ha)	Scenario 4 N --- (kg ha^{-1}) ---	Scenario 4 P	Scenario 5 Area (ha)	Scenario 5 N --- (kg ha^{-1}) ---	Scenario 5 P
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	37.7	128.2	28.8	37.7	128.2	28.8	36.3	128.2	28.8	34.9	128.2	28.8	36.3	92.2	12.8
19	48.9	128.2	28.8	45.1	128.2	28.8	48.9	128.2	28.8	48.9	128.2	28.8	48.9	95.9	13.3
26	207.7	353.3	122.7	207.7	353.3	122.7	203.0	354.0	123.0	198.9	354.0	123.0	203.7	117.5	15.4
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1536.1	31.1	9.3	1536.1	31.1	9.3	1502.3	31.1	9.3	1479.4	31.1	9.3	1513.2	30.4	9.1
13	14.9	31.1	9.3	14.9	31.1	9.3	14.9	31.1	9.3	14.9	31.1	9.3	14.9	31.1	9.3
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	53.7	194.6	30.4	52.5	194.6	30.4	53.0	194.6	30.4	52.9	194.6	30.4	53.5	122.9	16.1
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1.5	222.3	45.5	1.5	222.3	45.5	1.5	222.3	45.5	1.5	222.3	45.5	1.5	124.4	16.3
4	17.6	123.3	17.7	17.6	123.3	17.7	14.8	122.4	17.6	14.0	122.9	17.7	16.8	102.0	12.1
3	15.7	66.3	11.8	15.7	66.3	11.8	14.7	68.9	12.0	13.5	72.4	12.4	14.7	66.5	10.1
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	79.0	128.2	28.8	79.0	128.2	28.8	76.8	128.2	28.8	74.8	128.2	28.8	77.0	93.1	12.9
6	46.9	154.0	31.1	46.9	154.0	31.0	46.3	154.0	31.1	46.1	154.0	31.1	46.6	99.8	16.1
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[z] Scenario 1 = baseline; Scenario 2 = monitored BMPs; Scenario 3 = AOPA management practices; Scenarios 4 and 5 = alternative s cenarios.

Appendix 7. Manure applications simulated for the Whelp Creek Sub-watershed.

Table A7.1. Area and manure application rates of nitrogen (N) and phosphorus (P) for the different sub-basins and scenarios for the Whelp Creek Sub-watershed.

	Scenario 1[z]			Scenario 2			Scenario 3			Scenario 4			Scenario 5		
Sub-basin	Area (ha)	N ---- (kg ha^{-1}) ----	P	Area (ha)	N ---- (kg ha^{-1}) ----	P	Area (ha)	N ---- (kg ha^{-1}) ----	P	Area (ha)	N --- (kg ha^{-1}) ----	P	Area (ha)	N --- (kg ha^{-1}) ----	P
1	77.3	80.2	30.4	77.3	80.2	30.4	69.4	78.6	29.9	69.4	48.7	12.8	61.3	48.7	12.8
2	30.4	67.1	26.5	30.4	67.1	26.5	30.4	67.1	26.5	30.4	68.2	15.8	30.4	68.2	15.8
3	26.9	92.0	27.8	26.9	92.0	27.8	24.6	89.6	26.9	24.6	90.0	23.3	23.4	88.5	23.0
4	40.7	171.0	54.9	40.7	171.0	54.9	40.7	171.0	54.9	40.7	123.1	19.0	40.7	123.1	19.0
7	151.6	36.3	17.9	151.6	36.3	17.9	143.1	35.9	17.8	143.1	54.2	16.1	138.9	53.9	16.1
5	14.7	31.1	14.4	11.2	29.9	14.3	14.7	30.8	14.7	14.7	30.8	14.7	14.7	30.8	14.7
6	5.8	36.9	18.4	5.8	36.9	18.4	5.4	37.9	18.9	5.4	80.6	15.0	5.2	82.9	15.2
18	750.7	73.7	30.1	750.7	73.7	30.1	725.7	74.2	30.3	725.7	62.0	18.2	712.9	62.2	18.2
17	11.4	548.4	250.0	11.4	548.4	250.0	11.6	537.3	244.4	11.6	115.9	17.9	11.4	111.9	17.4
9	198.7	118.1	35.2	198.7	118.1	35.2	186.4	119.3	35.5	186.4	62.4	14.4	178.9	62.6	14.4
8	3.4	25.5	12.8	3.4	25.5	12.8	2.8	25.5	12.8	2.8	25.5	12.8	2.6	25.5	12.8
10	46.5	63.5	19.8	45.4	63.5	19.8	44.5	63.5	19.8	44.5	63.5	19.8	43.6	63.5	19.8
11	36.9	10.4	5.1	36.9	10.4	5.1	34.3	10.4	5.1	34.3	10.4	5.1	32.3	10.4	5.1
12	31.4	53.8	11.9	31.4	53.8	11.9	31.4	53.8	11.9	31.4	53.8	11.9	31.4	53.8	11.9
16	181.6	50.4	18.1	181.6	50.4	18.1	175.1	50.5	18.2	175.1	76.6	15.8	171.1	76.7	15.8
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	634.6	53.0	17.0	633.3	53.6	17.2	611.9	53.4	17.3	611.9	51.8	11.2	601.8	51.7	11.2
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	11.0	41.2	2.7	11.0	41.2	2.7	10.2	41.4	2.7	10.2	41.4	2.7	9.8	41.5	2.7
19	25.4	20.4	8.3	25.4	20.4	8.3	25.4	20.4	8.3	25.4	20.4	8.3	25.4	20.4	8.3
20	6.5	25.8	9.7	6.5	25.8	9.7	6.5	25.8	9.7	6.5	33.5	9.7	6.5	33.5	9.7

[z] Scenario 1 = baseline; Scenario 2 = monitored BMPs; Scenario 3 = AOPA management practices; Scenarios 4 and 5 = alternative s cenarios.

Appendix 8. Inventory of available datasets and their sources for modelling provincial-scale watersheds.

Dataset	Source	Website link
Elevation	NASA ASTER G-DEM: 30m DEM	J:\Drafting\GISMaster\Elevation\Meti_NASA_Global_Digital_Elevation_Model\GeoTIF
	1:250 000 25m DEM	J:\Drafting\GISMaster\Elevation\dem-all
Land use / land cover	AFSC: 2006 Land Cover Classification Project, 56m resolution	J:\Drafting\GISMaster\Land_Cover\AFSC_landcover\t83\december_2006.pdf J:\Drafting\GISMaster\Land_Cover\metadata\Final Report.pdf
	AAFC: Circa 2000 Land Cover for Agricultural Regions, 30m resolution	http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1227635802316&lang=eng
	WGTPP: 1995, 25m resolution	J:\Drafting\GISMaster\Land_Cover\wgtpp_landcover
Soil	AGRASID 3.0: Alberta Soil Information Centre	http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag3249
Climate data	ARD	http://www.agric.gov.ab.ca/app116/stationview.jsp Shen et al. 2000. Interpolation of 1961-1997 daily climate data onto Alberta polygons of ecodistrict and soil landscapes of Canada. 60 pp. + figures.
Surface water quality	ESRD	http://environment.alberta.ca/01288.html http://www.albertawater.com/index.php?option=com_awp&task=simple
	Environment Canada	http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm
	Alberta Agriculture AESA program	http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/irr12647
Surface water quantity	Environment Canada	http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm
	ESRD	http://environment.alberta.ca/01288.html http://www.albertawater.com/index.php?option=com_awp&task=simple

Dataset	Source	Website link
Surface and ground water usage	ESRD – Water for Life	AENV allocation amounts – For Red Deer – Andrew Patton – Water Admin. Engineer http://www.assembly.ab.ca/lao/library/egovdocs/2007/alen/164708.pdf http://www.environment.alberta.ca/apps/basins/default.aspx?Basin=7
Reservoir specifications	ESRD – Water Management Operations	Rob.hibbert@gov.ab.ca
Lake specifications and water quality	Alberta Geological Survey ESRD	http://www.ags.gov.ab.ca/publications/pubs.aspx?series=dig http://environment.alberta.ca/01288.html
Groundwater	Hydrogeological Consultants Ltd. and Alberta Geological Survey ESRD Water Well Information Database	http://www.hcl.ca/items/rgwa.asp http://www.ags.gov.ab.ca/publications/pubs.aspx?series=dig http://environment.alberta.ca/01314.html
Farm operations	Statistics Canada Census of Agriculture NRCB – Confined feeding operation data	J:\Drafting\GISMaster\Census http://www.statcan.gc.ca/ca-ra2006/index-eng.htm http://www.statcan.gc.ca/ca-ra2001/index-eng.htm http://www.nrcb.gov.ab.ca/contact/default.aspx
Wastewater treatment plant	Contact individual municipalities	http://environment.alberta.ca/apps/RegulatedDWQ/default.aspx
Crop prices	AFSC price lists ARD Agricultural Statistics Yearbook ARD AgriProfit$	http://www.afsc.ca/Default.aspx?cid=82&lang=1 http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex13714 http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ10237

Dataset	Source	Website link
Livestock prices	ARD Statistics and Data Development Branch internal databases	
	ARD AgriProfit$	http://agapps16.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ8557
Crop yields	ARD Agricultural Statistics Yearbook	http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex13714
	Statistics Canada Census of Agriculture	http://www.agriculture.alberta.ca/app21/infopage?cat1=Statistics&cat2=Census
Livestock populations	Statistics Canada Census of Agriculture	http://www.agriculture.alberta.ca/app21/infopage?cat1=Statistics&cat2=Census
Crop and livestock production cost profiles	ARD AgriProfit$	http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ10237 http://agapps16.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ8557
Fertilizer and pesticide prices (indices)	ARD Statistics and Data Development Branch AIMS Database	http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd13949

Appendix 9. List of available data from the Census of Agriculture.

Variable name	Variable description
farms	Total number of farms and area
Crop related	
crorgny	Total number of farms producing certified organic products - Farms Reporting
orgfvny	Fruits, vegetables or greenhouse products - Farms Reporting
orgfcny	Field crops (grains, oilseeds, etc.) - Farms Reporting
organny	Animals or animal products (meat, milk, eggs, etc.) - Farms Reporting
tfarea	Total area of farms - Farms Reporting and area
aowned	Total area owned - Farms Reporting and area
tlsrtcs	Total area rented, leased or crop shared from all sources - Farms Reporting and area
alsdgov	Total area leased from governments - Farms Reporting and area
arnted	Total area rented or leased from others - Farms Reporting and area
acrpshr	Total area crop shared from others - Farms Reporting and area
size1 to size14	Total farm area (under 4 hectares up to 1425 hectares and over) - Farms Reporting
all individual crops grown	Number of farms and area for wheat, barley, corn, canola, etc.
tforage	Total, forage land - Farms Reporting and area
cultld	Cultivated area - Farms Reporting and area
summrf	Summerfallow - Farms Reporting and area
impast	Tame or seeded pasture - Farms Reporting and area
unimpst	Natural land for pasture - Farms Reporting and area
fertil	Use of commercial fertilizer - Farms Reporting and area
manure	Total, manure - Farms Reporting and area
msolid	Manure application using a solid spreader - Farms Reporting and area
mirrig	Manure application using an irrigation system - Farms Reporting and ar ea
mliqsur	Manure application using a liquid spreader (on surface) - Farms Reporting and area
mliqinj	Manure application using a liquid spreader (injected) - Farms Reporting and area
manuprd	Production of manure - Farms reporting and mass
kgnitro	Nitrogen in manure - Farms reporting and mass
herbci	Use of herbicides - Farms Reporting and area
insecti	Use of insecticides - Farms Reporting and area
fungic	Use of fungicides - Farms Reporting and area
ncroprot	Crop rotation - Farms Reporting
nprmgras	Permanent grass cover - Farms Reporting
ncovcrop	Winter cover crops - Farms Reporting
ncontour	Contour cultivation - Farms Reporting
nstripcr	Strip-cropping - Farms Reporting
ngraswat	Grassed waterways - Farms Reporting
ngrmanny	Green manure crops for plough-down - Farms Reporting
nmchcpny	Mechanical or hand weeding of crops - Farms Reporting
nwindyes	Windbreaks or shelterbelts - Farms Reporting
tilconv	Tillage incorporating most of the crop residue into soil – Farms Reporting and area
tilcons	Tillage retaining most of the crop residue on the surface - Farms Reporting and area
tillno	No-till seeding or zero-till seeding - Farms Reporting and area
chemsf	Weed control on summerfallow land, chemical only - Farms Reporting and area
tillsf	Weed control on summerfallow land, tillage only - Farms Reporting and area
combsf	Weed control on summerfallow land, tillage and chemical combination on the same land - Farms Reporting and area

Variable name	Variable description
Livestock related	
tcattl	Total cattle and calves - Farms Reporting and number
bulls	Bulls - 1 year and over - Farms Reporting and number
mlkcow	Dairy cows - Farms Reporting and number
bfcows	Beef cows - Farms Reporting and number
steers	Steers - 1 year and over - Farms Reporting and number
calfu1	Calves - under 1 year - Farms Reporting and number
heifer	Total heifers - 1 year and over - Farms Reporting and number
cattle	Selected cattle - Farms Reporting and number
topigs	Total pigs - Farms Reporting and number
tsheep	Total sheep and lambs - Farms Reporting and number
totplt	Total poultry - Farms Reporting and number
bees	Colonies of bees - Farms Reporting and number
horses	Horses and ponies - Farms Reporting and number
bison	Bison (buffalo) - Farms Reporting and number
deer	Deer (excluding wild deer) - Farms Reporting and number
lamas	Llamas and alpacas - Farms Reporting and number
Economics related	
accntny	Bookkeeping, payroll or tax preparation - Farms Reporting
lvcrpny	Livestock and/or crop record keeping - Farms Reporting
tottrc	Total tractors - Farms reporting, number, and market value
vehicle	Vehicles - Farms reporting, number, and market value
totcomb	Combines - Farms reporting, number, and market value
tswtmow	Swathers and mower-conditioners - Farms reporting, number, and market value
totbal	Balers - Farms reporting, number, and market value
tharvst	Forage harvesters - Farms reporting, number, and market value
tcultsd	Tillage, cultivation, seeding and planting equipment - Farms reporting, number, and market value
virrig	Value of irrigation equipment - Farms reporting and market value
totfcap	Total farm capital - Farms Reporting and market value
valulb	Total value of land and buildings - Farms Reporting and market value
vallvsk	Value of livestock and poultry - Farms Reporting and market value
ncap1 -ncap12	Total farm capital (under $50,000 - $2,000,000 and over) - Farms Reporting
rntexp	Rent and leasing of land and buildings - Farms Reporting and $ amount
tcshwge	Total wages and salaries - Farms Reporting and $ amount
fertpd	Fertilizer and lime purchases - Farms Reporting $ amount
chempd	Purchases of herbicides, insecticides, fungicides, etc - Farms Reporting and $ amount
seedpd	Seed and seedling purchases (excluding materials purchased for resale) - Farms Reporting and $ amount
feedpd	Total feed and supplement purchases - Farms Reporting and $ amount
lvstpd	Livestock and poultry purchases - Farms Reporting and $ amount
fuel	All fuel expenses (diesel, gasoline, oil, wood, natural gas, etc) - Farms Reporting and $ amount
totexp	Total farm business operating expenses - Farms Reporting and $ amount
salesxfp	Total gross farm receipts (excluding forest products sold) - Amount $