Application of the CEEOT Model on the central portion of the Red Deer River Watershed

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EXECUTIVE SUMMARY

In 2007, Alberta Agriculture and Rural Development (ARD) initiated the 6-yr Nutrient Beneficial Management Practices Evaluation Project (BMP Project). The BMP Project included a field study in two agricultural watersheds and at two irrigated field sites, as well as a computer modelling component. The modelling system 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).

The modelling component consisted of two phases. In Phase 1 (2007 to 2011), CEEOT was applied to the two BMP Project watersheds, (Indianfarm Creek Watershed and Whelp Creek Sub-watershed), and one of the field sites (Lower Little Bow field). In Phase 2 (2012), CEEOT was applied to a central portion of the Red Deer River (RDR) watershed, referred to as the RDR study area. This report summarizes Phase 2 of the project involving the RDR study area.

The CEEOT model was first calibrated and then BMP scenarios were assessed for the RDR study area. The RDR study area included the drainage area from the City of Red Deer to the Town of Drumheller, with a total drainage area of about 1,217,530 ha. The RDR study area represented about 25% of the entire RDR watershed. In addition to modeling the RDR study area, efforts were taken to understand implications at the sub-basin scale. The focus was on five sub-basins (Blindman River and Haynes, Threehills, Ray and Renwick creeks) as they had previous water quality monitoring data from the Alberta Environmentally Sustainable Agriculture (AESA) Project.

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

- evaluate the performance of CEEOT at the AESA sub-basin and RDR study area scales,
- estimate nutrient (nitrogen and phosphorus) and total suspended solids (TSS) exports from the RDR study area and its tributaries,
- assess the potential for BMPs to mitigate nutrient and TSS losses in the RDR study area and its tributaries, and
- estimate the economic effects of implementing selected BMP scenarios in the AESA sub-basins and RDR study area.

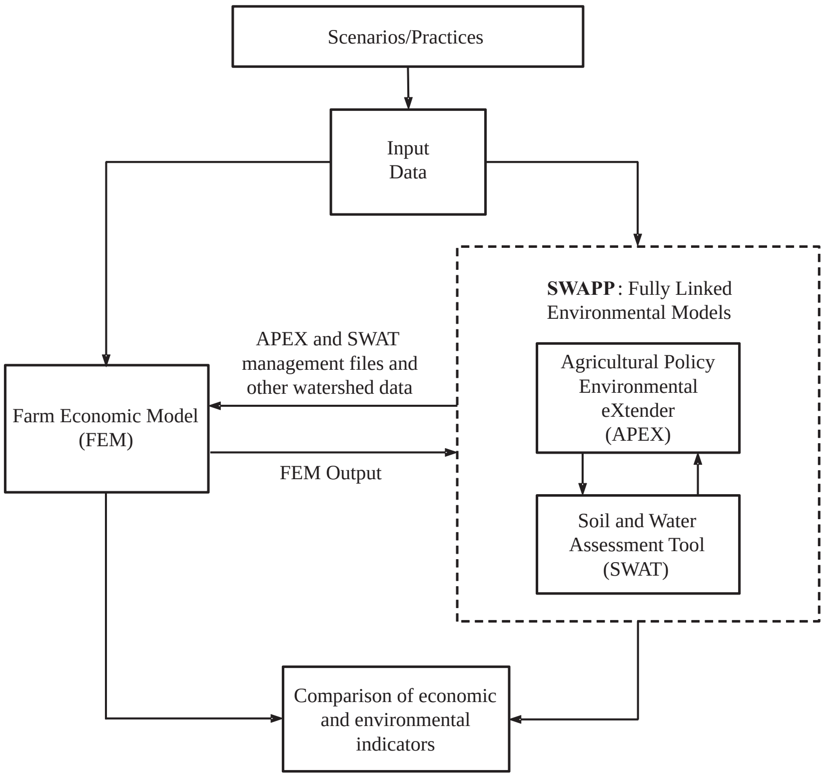
Development of Environmental and Economic Models

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

The mean monthly flows and TSS and nutrient losses obtained from the calibrated SWAPP were compared to measured values from the outlets of five AESA sub-basins and one RDR study area monitoring station to assess model performance. Two statistical methods (Nash-Sutcliffe E values and R^2 values) were used to evaluate the performance of the SWAPP model. The calibration results showed that SWAPP produced fairly good predictions of runoff and TSS, nitrogen (N), and phosphorus (P) losses at the outlets of the ASEA sub-basins and RDR study area.

Representative farms were established to serve as the basis for the FEM simulations and economic impact analysis. The composition of the farms were based primarily on farm data from the 2001 Census of Agriculture, including farm sizes, crop areas, and livestock inventories. A statistical algorithm was used to first disaggregate the Census data into a set of 4802 hypothetical farms, equal to the actual number of farms in the Census for that region. A clustering process was then employed to group these hypothetical farms into 196 clusters and define one representative farm for each cluster. Each representative farm was given a weight indicating how many actual RDR study area farms it represented.

Farm management data, such as crop yields and prices for most farm inputs and outputs, were obtained from a number of public databases available from ARD, Statistics Canada, and Alberta Financial Services Corporation. Field operations for a range of crops typical of the RDR study area were developed by ARD staff. The FEM model was populated by using Visual Basic scripts and



Schematic of the CEEOT modelling system.

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 costs 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.

Evaluation of BMP Scenarios

Seven scenarios were evaluated in the RDR study. Scenario 1 was the baseline scenario, which represented the typical farm practices as the status quo. The six additional scenarios represented the introduction of different sets of BMP practices that were modelled in the applicable areas and for representative farms in the study area. Scenarios 2 to 7 included a number of practices that were considered to be relevant for the RDR study area including manure management, grazing management, seasonal bedding, erosion control, riparian management, and wetland restoration.

Selected list of scenarios and associated beneficial management practices (BMPs) used for CEEOT simulations in the Red Deer River study area.[z]

	BMP List								
Scenario	P limit - crop removal rate	N inorganic limit - crop removal rate	Rotational grazing	Cattle restriction from water bodies	Excluding cattle from riparian areas in winter months	Minimum 100-m setbacks away from waterways	15-m grassed waterways	15-m buffer strips	Restore previously drained wetlands
1. Baseline	Producers are in compliance with the AOPA regulations[y]								
2. Manure management	X	X							
3. Rotational grazing			X	X					
4. Seasonal bedding					X	X			
5. Grassed waterways							X		
6. Riparian setbacks								X	
7. Wetland restoration									X

[z] More detail descriptions of the land-use management practices are provided in Sub-sections 7.1.1 through 7.1.7.

[y] AOPA = Alberta Agricultural Operation Practices Act.

The environmental indicators of runoff depth and the loss of TSS, organic N, organic P, nitrite N, phosphate P, total N, and total P were chosen to assess the scenarios. The results of the model simulations showed that BMP scenario performance was subarea and sub-basin specific.

Scenario 3 (rotational grazing) was shown to be clearly cost-effective in terms of environmental indicators and farm profits. In addition to moderate improvements to the environmental indicators, it also provided some increases in farm profits. On average, the increase was about \$4 ha^{-1} yr^{-1}, but the size of the benefit was shown to vary significantly among sub-basins. At the study area level, this represented more than \$3 million yr^{-1} in additional farm profits.

Scenario 2 (manure management) resulted in slightly improved farm profits in aggregate, though at the farm level it entailed a cost to some farms depending on size and type of operation. This scenario demonstrated a wide range of environmental results. At the study area outlet, total N and total P were reduced, while flow and TSS increased marginally. However, as with the economic indicators, these environmental indicators also varied considerably among sub-basins. This scenario was the only one that resulted in a significant increase in the amount of manure hauled off-farm, both for farms that were hauling manure off-farm in the baseline scenario as well as those that were not.

For most of the scenarios, there was a cost associated with the environmental improvements up to about \$5 ha^{-1} yr^{-1}. The cost was minimal for Scenario 4 (seasonal bedding and feeding sites); however, the environmental improvements were modest. Scenarios 5 (grassed waterways) and 7 (wetland restoration) resulted in modest improvements to most of the environmental indicators at modest costs. Scenario 6 (riparian setbacks) generally demonstrated significant environmental improvements but the costs were the highest. When riparian setbacks were modelled throughout the study area where applicable, the overall cost was almost \$4 million yr^{-1} for development and maintenance.

For all BMP scenarios that resulted in negative net returns, the impacts were either from a decline in revenues or an increase in cost or both. The size of the representative farms affected the scale of the economic impact when they were reported on a per hectare basis. Generally, the reduction per hectare in crop revenue resulting from the establishment of a BMP would be smaller on a large farm compared to a small farm.

Cost-effectiveness estimates provided insight into which scenarios generated the greatest loss reduction per dollar spent. Among the scenarios entailing a cost increase (or profit reduction) to farmers, Scenarios 2 and 4 were the most cost-effective with lower costs per unit of environmental improvements while Scenario 7 was the least cost-effective, especially in terms of organic P reductions.

Cost-effectiveness ratios and trade-off assessment showed that some scenarios were superior to others. 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 TSS reduction goals have been attained.

Critical Source Area

Critical source area analysis showed that some sub-basins have higher potential for generating greater amount of flow, sediment, and nutrients. Sub-basin 1 produced the largest amount of flow, sediment, and nutrients among all RDR sub-basins. It was estimated that 12% and 37% of total RDR study area exported 49% and 74% of TN and TP, respectively. Averaged among seven environmental indicators (TSS, ON, OP, NO_3-N, PO_4-P, TN, and TP), the critical source area was 20% of the total RDR study area; whereas, and the critical source area contributed 65% to the total load of the environmental indicators

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1 INTRODUCTION

1.1 Background

The quality of water in Alberta's rivers and lakes is a major concern to the public, industry, and government. Human activities, including agriculture, can have a negative impact on water quality. Studies in Alberta have shown that agricultural practices have caused water quality degradation in the province (CAESA 1998; Lorenz et al. 2008). An 8-yr study of 23 agricultural watersheds in Alberta showed that as agriculture intensity increased, water quality deteriorated in terms of higher concentrations of total N and total P (Lorenz et al. 2008). They also found that pesticide detection and concentration increased with agricultural intensity in watersheds.

To address water quality issues related to agriculture, beneficial management practices (BMPs) have been promoted to reduce nutrient and total suspended solids (TSS) loss from agricultural land to surface water, as well as reduce fecal contamination of water by livestock and manure. In recent years, there has been a need to evaluate the environmental effectiveness and economics of BMPs at field and watershed scales. In Alberta, the Nutrient Beneficial Management Practices Evaluation Project (BMP Project) was initiated in 2007 to evaluate BMPs in two watersheds and at two irrigated fields in the province (ARD 2014). The BMP Project was a 6-yr field and modelling project. The BMP field study monitored and evaluated BMPs at several field-scale sites in the study watersheds. The effects of implemented BMPs were measurable at the field scale, but not at the watershed-scale (i.e., at the watershed outlet). The lack of measurable effects at the watershed scale was because BMPs were implemented at only few sites and represented a small percentage of the drainage area in the study watersheds. Additionally, the effects of agricultural practices on water quality at a larger watershed scale can be difficult to measure and understand because of the (1) complexity of natural processes that occur in large watersheds and rivers, (2) diversity of soil, landscape, and land management practices, (3) variability of climatic conditions, (4) cumulative effect of different sources of contaminants entering the surface water, and (5) expense to carry out watershed-scale evaluation studies.

Comprehensive watershed management models can be effective in accounting for the complexity at the larger watershed scale. These models can identify the main factors that contribute to water quality degradation and provide recommendations to managers about alternative land management practices. 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 have been 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 the BMP Project, several beneficial management practices (BMP) were evaluated using the Comprehensive Economic and Environmental Optimization Tool (CEEOT) in the project's two watersheds (Indianfarm Creek Watershed and Whelp Creek Sub-watershed) and one of the irrigated field sites (Lower Little Bow Field) (Jedrych et al. 2014). One of the objectives of the BMP Project was to model the cumulative impacts of BMPs on water quality at a watershed scale (ARD 2014). Modelling the Indianfarm Creek (14,145 ha) and Whelp Creek (4595 ha) watersheds and the Lower Little Bow Field (83 ha) was Phase 1 of the modelling component, and this phase benefited from the collection of extensive water quality and land-use data during the BMP field study. The goal is to apply the CEEOT model to other and even larger watersheds in the province, without having to collect new data, and use exiting data for targeted watersheds. In the current study (i.e., Phase 2), the CEEOT model was applied to a central portion of the Red Deer River Watershed. The model was first calibrated using existing data and then a number of BMP scenarios were assessed by predicting changes in water quality and economic parameters.

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 APEX and SWAT models were integrated into the SWAPP (SWAT/APEX Program) module of the program to provide reliable simulation of detailed field processes through APEX and still take advantage of the large watershed routing capabilities of SWAT (Osei et al. 2000, 2008b). 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 farm-field, stream-watershed, and river-basin scales. As well, it is able to simulate the effects of land-use changes on soil and water quality under snowmelt conditions. Further details about the CEEOT model are in Osei et al. (2000) and Jedrych et al. (2014).

1.2 Overview of the Red Deer River Study

A central portion of the Red Deer River (RDR) watershed was selected for this application study of the CEEOT model and BMP evaluation. The selected potion of the watershed, referred to as the RDR study area, included the drainage area along the RDR reach from the City of Red Deer (upstream) to the Town of Drumheller (downstream), with a total drainage area of about 1,217,530 ha (Figure 1.1). The RDR study area represented about 25% of the entire RDR Watershed (Red Deer River Watershed Alliance 2009), and was 86-fold and 265-fold larger than the Indianfarm Creek and Whelp Creek watersheds, respectively, which were used in the Phase 1 modelling study (Jedrych et al. 2014). The RDR study area was selected in part because five sub-basins within the study area were used as water quality monitoring sites (sub-basin outlets) in the Alberta Environmentally Sustainable Agriculture (AESA) Water Quality Program from 1999 to 2006 (Lorenz et al. 2008). These five AESA sub-basins ranged in size from 4,523 to 35,394 ha, and in total represented nearly 7% of the RDR study area. The 8-yr AESA water quality database included measurements of total phosphorus (TP), total dissolved phosphorus (TDP), total nitrogen (TN), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), pH, temperature, fecal coliforms, *E. coli*, and a variety of pesticides from 1997 to 2006. In addition, there were three Alberta Environment and Sustainable Resource Development (ESRD) long-term water quality monitoring sites along the reach of the RDR within the study area. The RDR study area was characterized as having diverse and relatively high intensity agriculture (Alberta Environment 2007). The study area also had a wide variety of hydrologic conditions typical of six natural regions of Alberta. Most of the RDR study area was in the Central Parkland Natural Sub-region. The remaining portion of the study area was in the Lower Foothills, Central Mixedwood, Dry Mixedwood, Foothills Fescue, and Northern Fescue natural regions.

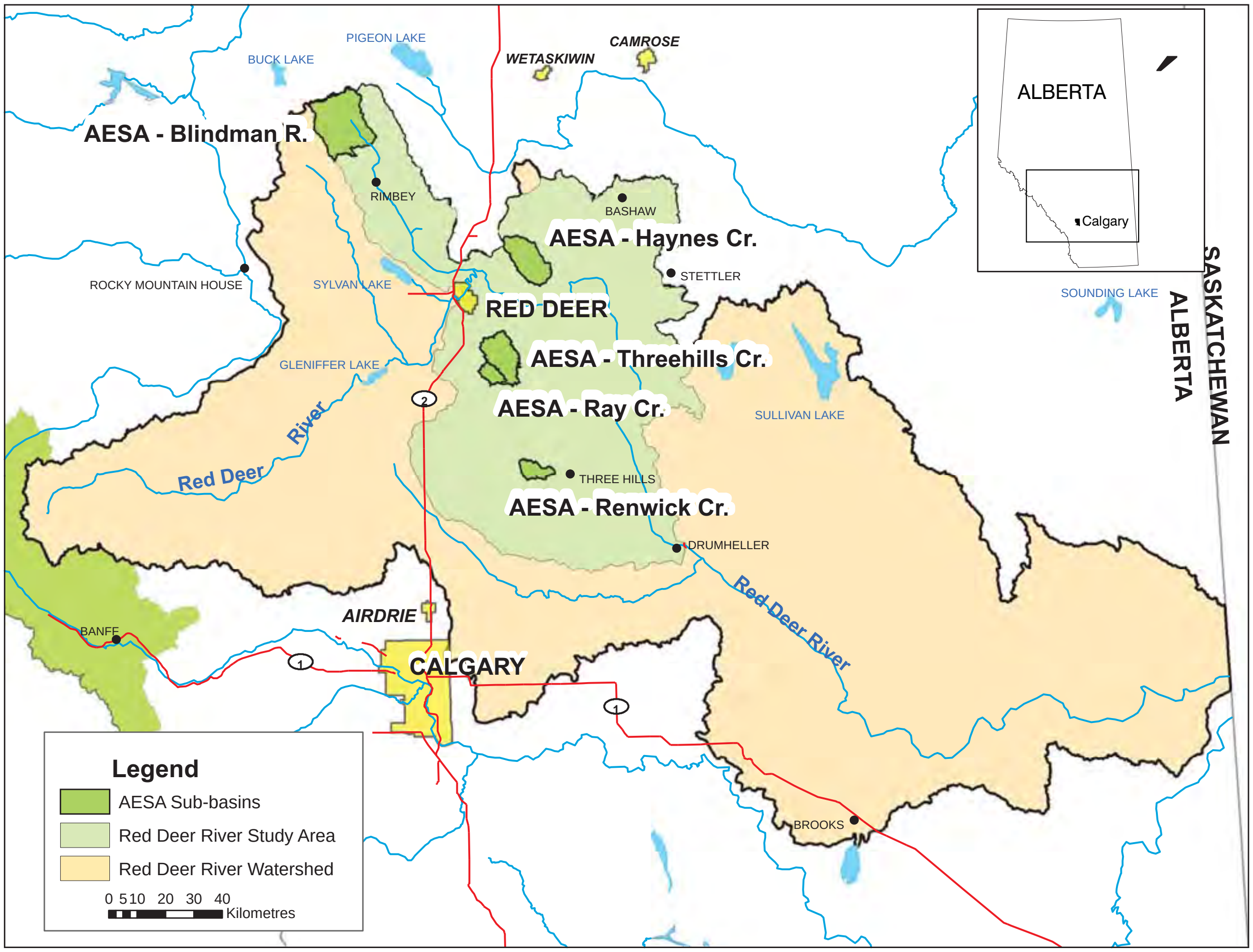

Figure 1.1. The Red Deer River study area used in the study and the five AESA sub-basins.

The RDR study was a collaborative work by ARD and the Texas Institute for Applied Environmental Research (TiAER). For this study, TiAER (1) developed CEEOT input data files, (2) completed CEEOT calibration for selected RDR stations, (3) developed and simulated BMP scenarios in CEEOT, (4) reviewed and interpreted BMP scenario simulation results, (5) enhanced the CEEOT model by embedding new macros and extension tools to facilitate seamless CEEOT applications in a wide variety of Alberta watersheds, and (6) assisted in the preparation of the final report.

The objectives of this study were to:

- evaluate the performance of CEEOT at the AESA sub-basin and RDR study area scales,
- estimate nutrient (P and N) and total suspended solid (TSS) exports from the RDR study area and its tributaries,
- assess the potential of selected BMP scenarios to mitigate nutrient and TSS losses in the RDR study area and its tributaries, and
- estimate the economic effects of implementing selected BMP scenarios in the RDR study area.

2 SWAPP MODEL INPUT DATA DEVELOPMENT FOR RED DEER RIVER STUDY AREA

2.1 Topographical Data and Study Area Configuration

Digital Elevation Model (DEM) data were obtained via the joint release of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) data by the Ministry of Economy, Trade, and Industry of Japan, and the United States National Aeronautics and Space Administration (ASTER GDEM 2009). The resolution of the DEM is 30 m with estimated accuracies of 20 and 30 m at 95% confidence for vertical and horizontal data, respectively (ASTER GDEM Validation Team 2009). The DEM has been utilized to calculate the study area characteristics such as sub-basin drainage area, slope length and steepness, and stream geometry using ArcGIS interface. The ArcGIS analyses of the DEM data for the RDR study area showed that surface elevation ranged from 504 to 1103 m and the area was approximately 1,217,530 ha in size (Figure 2.1a). Sub-basins were delineated based on a minimum size threshold of 4000 ha, the location of existing water quality and quantity monitoring stations, and the location of major water bodies. Ultimately, the RDR study area was subdivided into 41 sub-basins (Figure 2.2).

Two similar area units are used to provide certain landscape input data to SWAT and APEX. The Hydrologic Response Units (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 sub-basin can change as biophysical characteristics change, such as the implementation of BMPs. Where HRUs 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, consequently, a combination of HRUs and subareas are required. The advantage of this configuration approach is that the SWAPP-predicted results represent cumulative effects of BMP implementation at different scales within a watershed.

ArcGIS allows definition of multiple HRUs based on the assumed land use, soil, and slope thresholds within each sub-basin. In the RDR study, the land-use threshold was assumed to be 10%. Land-use types that covered less than 10% of the sub-basin area were excluded from the HRU formulation. In addition, soil and slope thresholds were assumed to be 15 and 25%, respectively, and specific soil series or slope types less than these thresholds in a sub-basin were also excluded from the HRU formulation. The actual number of HRUs was determined by overlaying the newly defined land use, soil, and slope coverage, and then identifying unique combinations within each sub-basin. In the process, 1236 different HRUs were defined in the RDR study area.

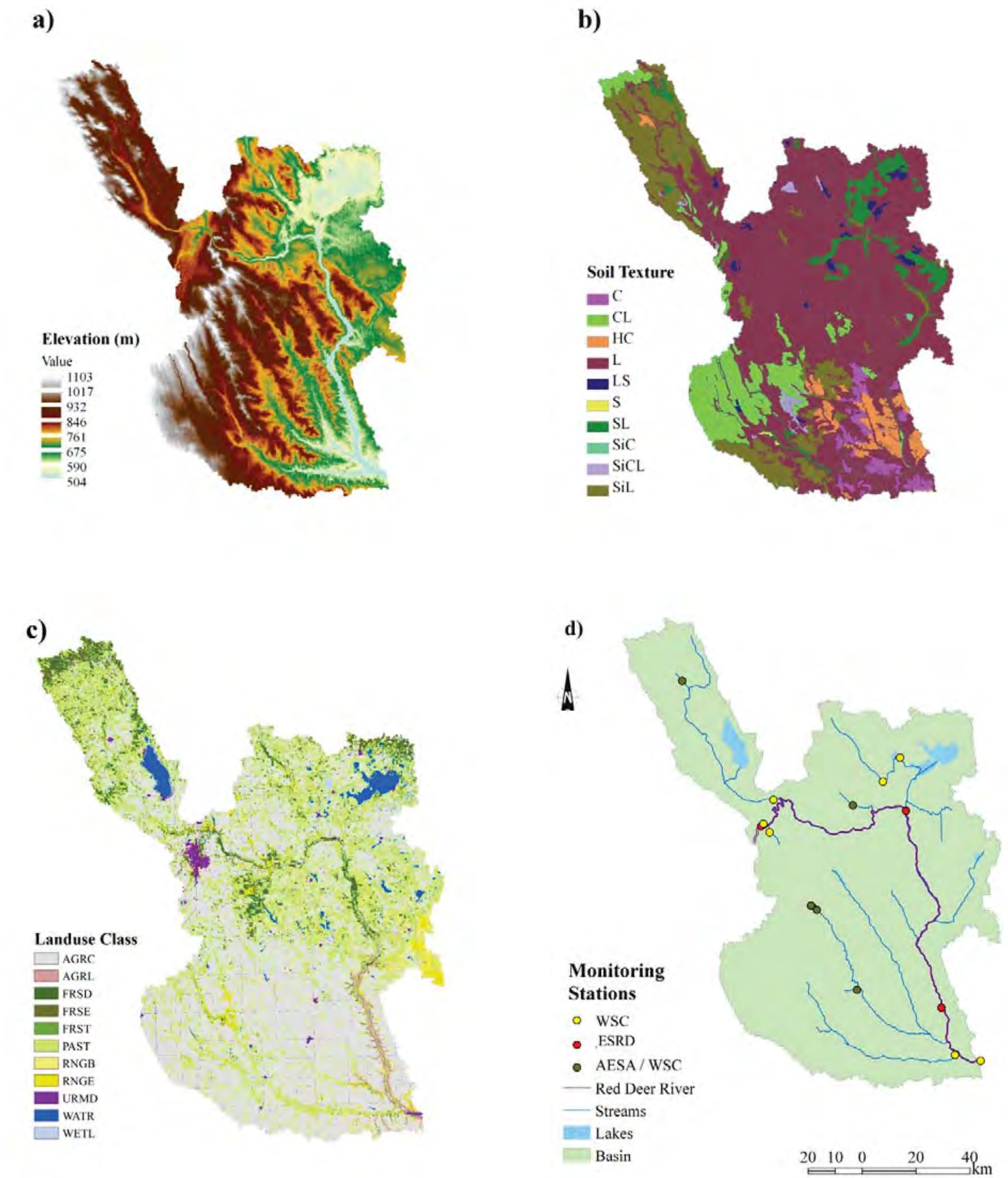

Figure 2.1. Maps of Red Deer River study area selected for CEEOT model application showing distribution of (a) elevation; (b) soil texture; (c) land-use class; and (d) water monitoring stations for Water Survey of Canada (WSC), Alberta Environment Sustainable Resource Development (ESRD), and Alberta Environmentally Sustainable Agriculture Program (AESA).

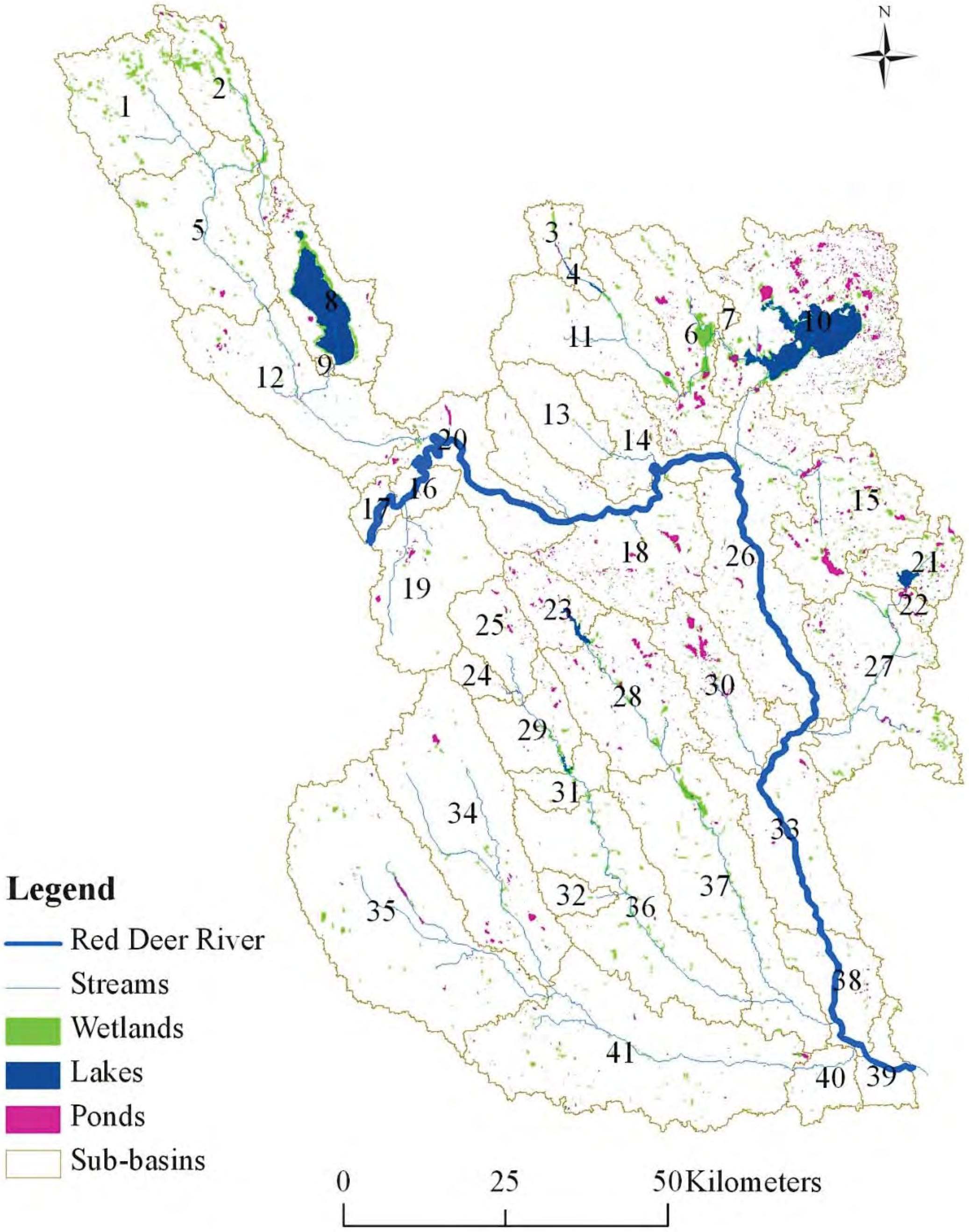

Figure 2.2. Distribution of streams, wetlands, lakes, ponds, and sub-basins within the Red Deer River study area.

2.2 Soil Data

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 dominate and co-dominate soil series; however, there is no information on their geographical location within polygons. Therefore, for this modelling project, only dominate soil series were selected. The RDR study area contained 89 different dominate soil series with soil properties data for up to nine layers to a maximum depth of 1.7 m. These soil series were grouped into ten different soil texture classes. (Figure 2.1b)

The soil physical and chemical parameters have a major impact on predicted movement of water within a soil profile and on predicted water balance within a HRU. Jedrych et al. (2014) presented a list of soil physical properties and described the data sources and methods that were used to calculate these values for SWAT and APEX. A similar approach was taken to calculate soil physical properties for the RDR study area.

To initiate simulations, SWAT and APEX required soil-chemical parameters such as concentrations of NO_3-N, organic N (ON), water soluble P (WSP), and organic P (OP) for all soil layers. Since measured values were not available at the AGRASID soil polygon scale, the model default values were used instead.

2.3 Land Management Data

The land management input data for the CEEOT model was generated using three datasets: land-use data, Canadian Census of Agriculture data, and field operation data. The following sub-sections provide more details about these datasets.

2.3.1 Land-Use Data

A 30-m raster dataset of land-use and land-cover data was acquired from Agriculture and Agri-Food Canada (AAFC 2000). The dataset was derived from classifying Landsat imagery acquired around 2000 (Figure 2.1c). The land-use data were selected because specific focus was given to differentiating annual crops from perennial crops and among pasture, rangelands, and forests. The land-use map of the modelled RDR study area is indicative of the diversified intensity of agriculture in the study area, as annual cropland (44.2%) and perennial cropland and pasture (49.3%) comprise about 93% of the landscape. The data showed that the southern portion of the study area primarily consisted of annual crops, while the northern portion was dominated by perennial crops. In addition to 2000 Landsat imagery, the 2011 Landsat imagery was used to estimate the extent of wetlands drainage during the 2000 to 2011 period.

2.3.2 Canadian Census of Agriculture Data

The 2001 Census of Agriculture (Statistics Canada 2001) database includes a wide variety of agricultural production variables such as crop type, farm area, area of manure and commercial fertilizer application, N application rates, and manure production. The collected Census data were initially reported at the municipality scale and later sorted by Gross Watersheds as developed by the former Prairie Farm Rehabilitation Administration (PFRA) (Cherneski and Ackerman 1998). In the study, the data were used for the development of representative farms and CEEOT land management input files. Tables 2.1 and 2.2 provide summaries of land-use categories and manure application rates that were extracted from the 2000 Landsat imagery and Census data and used for preparation of the management input files.

The Census data showed that manure was applied to only a small portion of the total cropland area, ranging from 2 to 7%. The calculated manure application rates ranged from 33 to 137 Mg ha^{-1} among the sub-basins, with an average of 88 Mg ha^{-1} (Table 2.2). The average rate was considered typical for livestock-intensive watersheds in Alberta.

Table 2.1. Summary of land-use categories derived from the 2000 Landsat imagery data and from the 2001 Census data (Statistics Canada 2001).

Land-use category	SWAT code ID	Area (ha)	Fraction of total area (%)
Pasture	PAST	442,983	36.4
Forest - deciduous	FRSD	25,863	2.1
Spring wheat	SWHT	150,929	12.4
Barley	BARL	219,533	18.0
Canola - Argentine	CANA	82,325	6.8
Field peas	FPEA	34,302	2.8
Alfalfa	ALFA	82,325	6.8
Fallow	AGRL	51,490	4.2
Hay	HAY	75,465	6.2
Water (lakes)	WATR	25,867	2.1
Range - brush	RNGB	14,656	1.2
Residential - medium density	URMD	3,779	0.3
Range - grasses	RNGE	8,014	0.7
Total		1,217,531	100.0

Table 2.2. The average annual manure nutrient application rates derived from the 2001 Census data (Statistics Canada 2001).

Sub-basin ID	Manure	Manure N	Manure P
	------------------------------- (kg ha^{-1})	-------------------------------	
1	57,036	314	234
2	137,068	726	548
3	86,689	477	355
4	86,689	477	355
5	76,364	428	313
6	87,673	465	351
7	87,673	465	351
8	55,616	295	217
9	55,616	295	217
10	65,821	349	263
11	86,689	477	355
12	76,364	428	313
13	76,333	427	321
14	84,931	467	348
15	104,976	577	430
16	84,931	467	348
17	98,911	524	396
18	84,931	467	348
19	63,133	335	246
20	84,931	467	348
21	83,629	460	343
22	83,629	460	343
23	121,853	646	487
24	107,719	592	442
25	107,304	601	451
26	104,976	577	430
27	104,976	577	430
28	121,853	646	487
29	74,617	425	313
30	104,976	577	430
31	na[z]	na	na
32	32,774	180	134
33	104,976	577	430
34	75,195	421	308
35	92,424	518	379
36	91,520	513	375
37	104,976	577	430
38	104,976	577	430
39	104,976	577	430
40	82,114	484	361
41	82,114	484	361

[z] na = not available.

2.3.3 Field Operation Data

Crop rotations for the representative farms developed for the RDR study area included spring wheat, feed barley, canola, oats, field peas, alfalfa, tame hay, and tame pasture. Field operations data were generated by ARD staff based on their understanding of the timing, range, and sequence of field operations. A range of field operations, from seeding, fertilizer application, cultivation, pesticide spraying, swathing, combining, and baling, were delineated sequentially per crop for the growing season. The same process was repeated for each representative farm type. The frequencies of farming operations were captured using ratios assigned to represent the number of times a field operation takes place during a 10-yr period. This representation also implicitly shows the frequency of crop rotation on a particular field. Yield data were also assigned to each crop based on provincial and regional averages. Examples of field operations data are in Table 2.3.

Machinery and equipment were assigned to each field operation from a machinery/equipment list developed for the RDR project.

Table 2.3. Examples of crop rotations and field operations by representative farm type.

	Approximate dates for field operations			
Crop rotations	Spray/plant	Fertilizer/herbicide	Combine	Cultivate
		Grain Farm 1		
Spring wheat	14 May/17May	17 May/3 Jun	25 Sep	12 Oct
Feed barley	20 May	20 May/3 Jun	25 Sep	10 Oct
Canola	18 May/ 22 May	22 May/ 6 Jun	5 Oct	-
Summer fallow	1 Jun	-	-	1 Oct
		Grain Farm 2		
Spring wheat	14 May/17May	17 May/3 Jun	25 Sep	12 Oct
Feed barley	20 May	20 May/3 Jun	25 Sep	10 Oct
Canola	18 May/ 22 May	22 May/ 6 Jun	5 Oct	-
Oats	25 May	25 May/17 Jun	12 Oct	17 Oct
Field peas	12 May	12 May/5 Jun	25 Aug	-
		Mixed Farm 1		
Spring wheat	17 May	17 May/3 Jun	25 Sep	10 Oct
Feed barley	20 May	20 May/3 Jun	25 Sep	10 Oct
Alfalfa	15 May	15 May	30 Jun[z]	-
Tame hay	-	10 Oct (Manure)	20 Aug	-
Tame pasture	-	-	-	-

[z] Second cut, every 3 or 4 years.

2.4 Climate Data

Daily records of maximum and minimum temperature, precipitation, wind speed, relative humidity, and solar radiation were obtained for 18 townships distributed throughout the RDR study area (Figure 2.3). Historical data were estimated for each township by extrapolating observed data from nearby weather stations (Shen et al. 2000). Records of daily precipitation, air temperature, wind speed, relative humidity, and solar radiation were compiled for the period from 1971 to 2005.

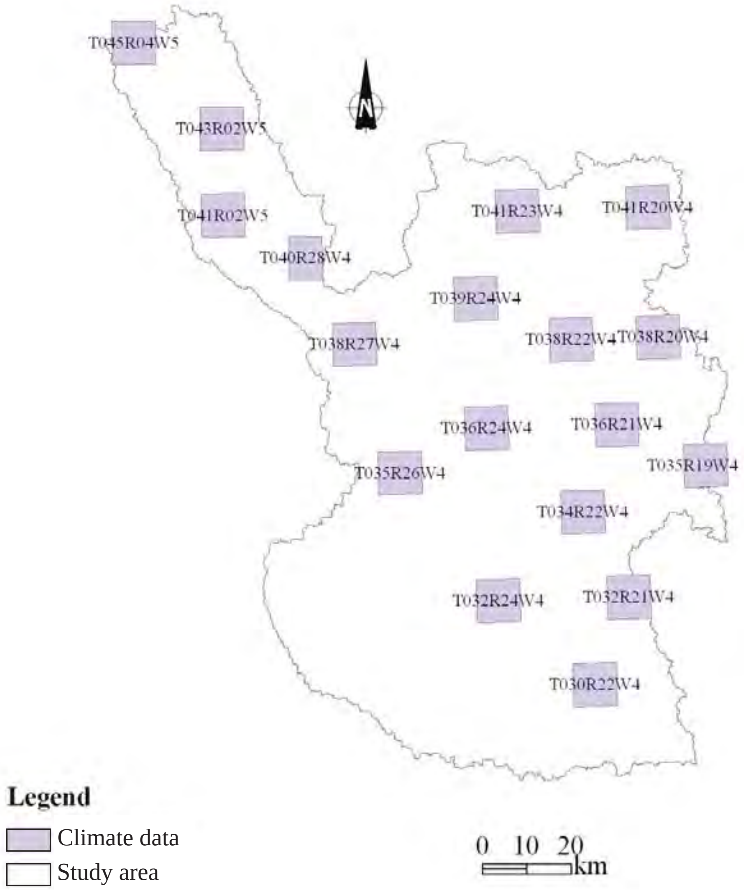

Figure 2.3. Distribution of township-scale climate input data for the Red Deer River study area used in SWAPP simulation.

2.5 Water Quality and Quantity Monitoring Stations

It is important to note that the availability of the existing water quality and quantity data varied among monitoring stations within the RDR study area because different agencies were involved in collecting these data. For example, ESRD had three long-term water quality sampling stations located along the river in the RDR study area (Figure 2.1d). Two of these stations did not include measured flow and TSS data and one station near Nevis contained flow data for only the 1944 to 1981 period (Table 2.4). The “HWY 2 bridge” station was located directly upstream of the City of Red Deer and the measured nutrient data were used in model input as a point source to represent the headwater loads of the RDR.

The RDR study area also included seven Water Survey of Canada (WSC) hydrometric gauging stations (Table 2.4). Two of these stations were on the main river stem and included flow data from 1970 to 2005 and sediment data from 1971 to 1984. The remaining five stations were on RDR tributaries and included only flow data collected from 1970 to 2005 (Figure 2.1d). Additional flow and water quality data were also available from five stations collected under the AESA Water Quality Project in cooperation with WSC, ARD, and AENV (Figure 2.1d). The AESA data were the most comprehensive because they included all parameters (flow, TSS, N, and P measurements) collected from 1997 to 2006.

The average monthly flow at the RDR study area inlet near the City of Red Deer was estimated at 42.1 $m^3 s^{-1}$ using 1975 to 2005 data from Station 05CC002 (data not shown). Water at Station 05CC002 is received from the upper part of the RDR Watershed with an area about 1,160,000 ha in size. In comparison, the average monthly flow at the outlet of the RDR study area at the Town of Drumheller (Station 05CE001, Table 2.4) was estimated at 47.6 $m^3 s^{-1}$ for the same period. This indicates that the RDR study area between the inlet near Red Deer and the outlet near Drumheller supplied only about 13% of the flow measured at the Station 05CC002. Even though the RDR study area was about the same size (1,217,530 ha) as the upper part of the RDR Watershed, the study area contributed only a small percentage of flow at Station 05CC002. In addition, the analysis of flow hydrographs (data not shown) indicated that the river peak flow usually occurs during the June to July period. The monthly peak flows were 92.5 and 99.6 $m^3 s^{-1}$ at Stations 05CC002 and 05CE001, respectively, from 1975 to 2005.

The TSS data were available from 1971 to 1984 for Station 05CC002 and from 1974 to 1984 for Station 05CE001 (Table 2.4). The estimated average monthly export coefficient for TSS was 0.011 Mg ha^{-1} at the Station 05CC002 (upstream) and 0.025 Mg ha^{-1} at the Station 05CE001 (downstream). An additional analysis of the TSS data (not presented in this report) showed that the RDR study area between the City of Red Deer and Town of Drumheller exported slightly more than 78% of the total TSS load calculated for the 05CE001 station.

The average monthly flow at the outlets of the five AESA sub-basins (Table 2.4) ranged from 0.04 $m^3 s^{-1}$ at Renwick Creek to 1.59 $m^3 s^{-1}$ at Blindman River. Contrary to the RDR peak flows, the AESA sub-basin peak flows occurred during spring (March-April) runoff events. Average monthly export coefficients ranged from less than 0.001 Mg ha^{-1} at Ray Creek to 0.005 Mg ha^{-1} at Blindman River for TSS, 0.01 kg ha^{-1} at Ray Creek to 0.156 kg ha^{-1} at Blindman River for TN, and 0.010 kg ha^{-1} at Ray Creek to 0.022 kg ha^{-1} at Blindman River for TP.

Table 2.4. Summary of available water quality data used for model calibration related to monitoring stations.

Station name	Station ID	Availability of water quality data and monitoring periods							
		Flow	TSS	NO_3-N	PO_4-P	Org N	Org P	Total N	Total P
Alberta Environment and Sustainable Resource Development long-term river-network monitoring stations									
RDR at HWY 2 bridge				1987-05	1987-05	1987-05	1987-05	1987-05	1987-05
RDR near Nevis		1944-58		1999-05	1999-05	1999-05	1999-05	1999-05	1999-05
RDR at Morrin Bridge				1987-05	1987-05	1987-05	1987-05	1987-05	1987-05
Water Survey of Canada (WSC) hydrometric gauging stations									
RDR at Red Deer	05CC002	1971-05	1971-84						
Waskasoo Creek near Red Deer	05CC011	1984-05							
Blindman River near Blackfalds	05CC001	1970-05							
Parlby Creek near Mirror	05CD902	1984-05							
Parlby Creek at Alix	05CD007	1984-05							
Kneehills Creek at Drumheller	05CE002	1970-05							
RDR near Drumheller	05CE001	1970-05	1974-84						
Alberta Environmental Sustainable Agriculture and WSC monitoring stations									
Blindman River	05CC008	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06
Haynes Creek	05CD006	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06
Ray Creek	05CE010	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06
Threehills Creek	05CE018	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06
Renwick Creek	05CE011	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06	1997-06

It is important to note that in contrast to the water monitoring data, SWAPP separates P into phosphate phosphorus (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 TDP and particulate P (PP) fractions, respectively, as reported in Jedrych et al. (2014). In addition, it was assumed that:

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

2.6 Impoundment Data

Impoundments such as ponds, wetlands, and reservoirs greatly affect surface runoff and flood control within watersheds. The area distribution of impoundments in the RDR study area was estimated based on the wetland and water land-use categories identified in the above mentioned Landsat imagery data. First wetlands polygons were delineated. Then the water land-use category polygons were split into pond and reservoir land-use polygon categories based on the SWAT modelling assumption that ponds are located off the main rivers and reservoirs are located on the main river network (Figure 2.2). The reservoirs identified in this study included Gull and Buffalo lakes. For the RDR study area, it is estimated that the wetlands and reservoirs (including ponds) covered areas of approximately 21,240 and 25,867 ha, respectively.

2.7 Sub-basin and Subarea Scale Routing Sequence of Runoff in the RDR Study Area

Information on the sub-basin routing sequence is pertinent to a correct understanding of the environmental impacts of simulated scenarios at the sub-basin level and at the outlet of each sub-basin. 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 area are influenced by the values of the respective indicators in all upstream sub-basins.

The sub-basin-level (Figure 2.2) routing sequence for the RDR study area is presented in Figure 2.4. The upper portion of the RDR Watershed (i.e., upstream from Station 05CC002 and not modelled) was added as a point source input in Sub-basin 17 (RDR study area inlet). The wastewater treatment discharge from the City of Red Deer was also added as a point source in Sub-basin 16. The AESA monitoring stations (Blindman River, Haynes Creek, Ray Creek, Threehills Creek, and Renwick Creek) were represented as Sub-basins 1, 13, 24, 25, and 32, respectively. In addition, two reservoirs were simulated within the RDR study area: Gull Lake (R1) and Battle Lake (R2). The RDR study area outlet was Sub-basin 39. Between the inlet (Sub-basin 17) and the outlet (Sub-basin 39) of the study area, nine tributaries (Tr.1 to Tr.9) were modelled entering the main stem of the RDR (Figure 2.4).

The actual routing of surface flow at the subarea scale was much more complicated than at the sub-basin scale. This higher routing complexity was related to the larger number (1236) of subarea polygons and to the fact that a single subarea polygon in reality was a SWAT-scale HRU, which was a composite of a number of field polygons. Therefore, the actual routing sequence for individual subareas was very difficult to define within each sub-basin and it was beyond the scope of this project to establish. Consequently, for APEX modelling, the subarea routing sequence was generalize by assuming that annual crops, pastures, forests, and range lands were located upstream from wetlands within all RDR sub-basins. In this assumption, APEX simulations were conducted for each subarea within each sub-basin and then the results from all individual subareas (except wetlands) were added before being routed through the wetlands that were located downstream.

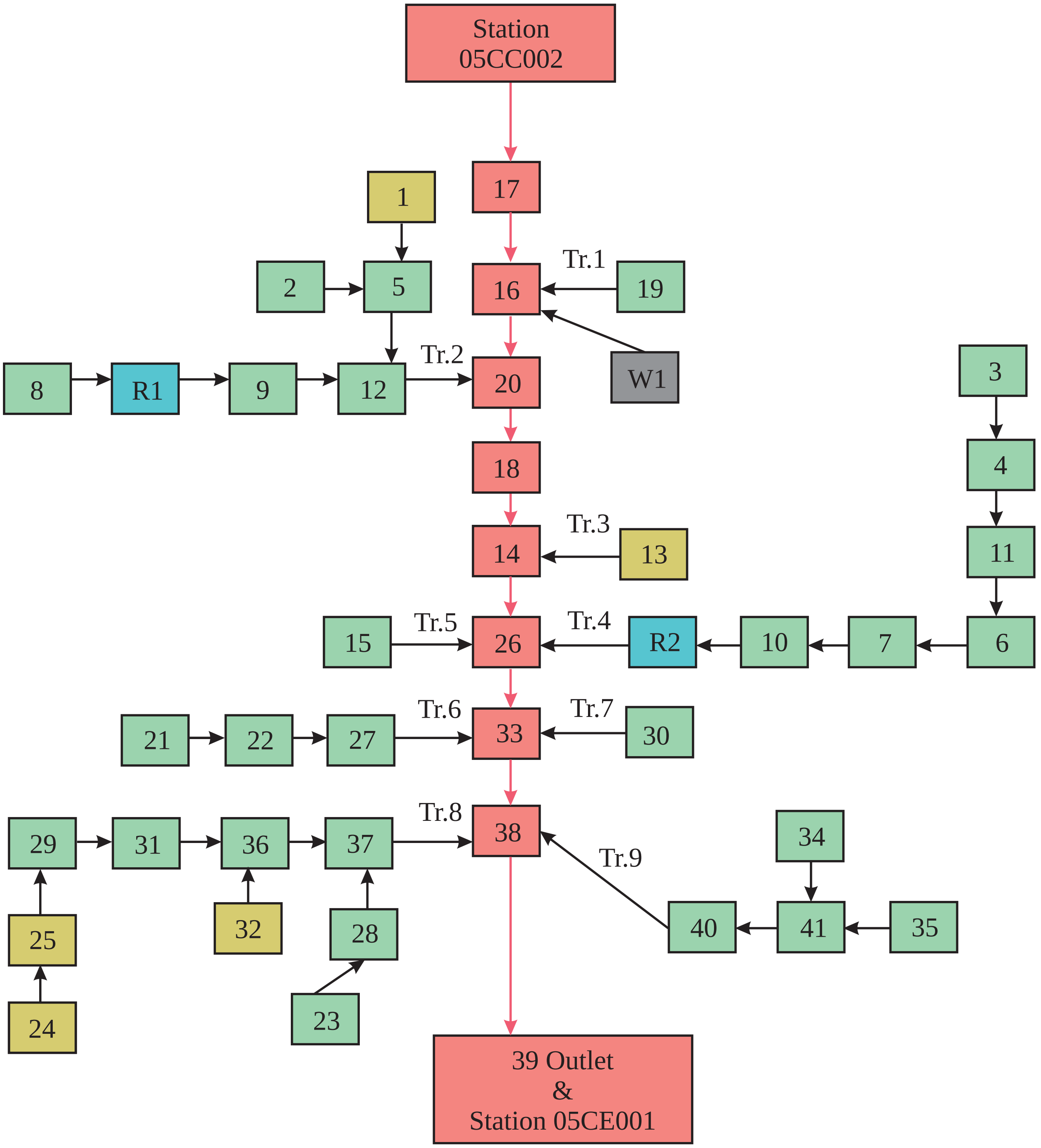

Figure 2.4. Diagram of sub-basins (1 to 41), reservoirs (R), tributaries (Tr.) and Red Deer wastewater discharge plant (W) routing sequence for the Red Deer River (RDR) study area model in SWAPP. The AESA sub-basin outlets are labelled as 1 (Blindman River), 13 (Haynes Creek), 24 (Ray Creek), 25 (Threehills Creek), and 32 (Renwick Creek).

3 FEM MODEL DATA DEVELOPMENT

3.1 Data Sources

Price data for most farm inputs and outputs were collected by ARD staff for the FEM simulations. Crop prices were collected from the Alberta Farm Financial Services Corporation website, as well as ARD and Alberta Canola Producers Commission databases. Fertilizer prices were collected from a farm input survey conducted by ARD staff.

3.2 Development of Representative Farms

Representative farms were established for the entire study area to serve as the basis for the FEM simulations and economic impact analyses. While APEX and SWAT simulations were conducted on HRU scale, the FEM simulations were based on the representative farm distributions, augmented with equipment complement information and farm management data typical of farms in the RDR study area. The representative farms were developed by applying data disaggregation and statistical clustering procedures to sub-basin-level aggregates of the Census of Agriculture for the RDR study area. The data disaggregation and statistical clustering procedures used were based on methodology used in the Comprehensive Economic and Environmental Optimization Tool – Macro Modelling System (CEEOT-MMS) program as reported in Osei et al. (2003).

The Census of Agriculture data for the RDR study area was aggregated into 23 PFRA-scale sub-basins. These sub-basins altogether contained data for 4802 farms in the RDR study area. Table A1 in Appendix 1 provides the entire list of farm attributes that were represented in the Census data. For each Census attribute and for each sub-basin, the number of farms with that attribute as well as the summation of the farm-level values of that attribute across the entire sub-basin was provided. This basic aggregate dataset was used to develop farm-level distributions in the data disaggregation step and then representative farms in the statistical clustering step.

Data disaggregation was performed by generating a statistical distribution of each farm attribute for each sub-basin that satisfied the Census aggregates for that sub-basin. Random number generation was used to generate the underlying distribution of each farm attribute assuming a discrete uniform distribution. Once the distribution of farm attributes was developed, the 4802 values for each attribute were mapped to other attributes to create a hypothetical set of 4802 farms that collectively mimicked the Census aggregates for each of the 23 sub-basins.

The set of hypothetical farms thus developed were grouped into clusters of farm types and sizes using the FASTCLUS procedure in SAS®. The optimal number of farm clusters was determined for each sub-basin by using the cubic clustering criterion and pseudo F statistic as explained by Osei et al. (2003). One representative farm was identified from among all the hypothetical farms within each cluster. The representative farm was defined as the farm closest to the centroid of the cluster.

The representative farms developed for the RDR study area are summarized in Table 3.1. In total, 196 representative farms were developed. Over half of the farms were crop farms, i.e., farms on which the main source of revenue came from crop sales. However, many of these farms also raised livestock. The crop farms are evenly divided among small, medium, and large size categories. Cattle farms are also prevalent in the RDR study area, though none of the cattle representative farms fell into the large farm size category. Swine and dairy farms were also present.

Based on the representative farm-type weightings developed through the clustering process, these representative farms were pro-rated upwards to span the total number of farms in the RDR study area. For example, the 39 small-cattle representative farms actually represent 1914 small-cattle farms in the RDR study area. These total farm numbers were used to translate the farm-level economic results of the FEM to economic results for the study area as a whole.

Once the representative farms were defined, additional data were obtained to augment the agricultural Census attributes that were used in the clustering process. Equipment and machinery data for different categories of representative farms were collected by ARD staff. Furthermore, input and output prices as well as farm management data were obtained by ARD staff from sources in Alberta.

Table 3.1. Number of representative farms types and total number of farms represented in the Red Deer River study area.

Farm type	Farm size	Number of representative farms	Number of farms in study area
Crop	Small	39	1914
	Medium	39	588
	Large	34	496
	Total	112	2998
Cattle	Small	37	819
	Medium	22	722
	Total	59	1541
Swine	Small	3	129
	Medium	9	70
	Large	7	7
	Total	19	206
Dairy	Medium	4	54
	Large	1	1
	Total	5	55
Turkey	Medium	1	2
Total	Total	196	4802

3.3 Management Data Input

Land management and economic data 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., TSS and nutrient loads) to FEM as well as to where FEM evaluated the economic impacts of changes in environmental factors (e.g., TSS and nutrient loads).

4 GAPS, ASSUMPTIONS, AND LIMITATIONS

4.1 Livestock Inventory and Manure Production

The 2001 Census data contains information on livestock inventories, but only limited information on livestock sales and purchases for the farms surveyed. Livestock inventory data were needed in simulations performed by all three models in CEEOT, but livestock purchase and sales data were only required by FEM. Livestock purchases for each farm type (e.g., feeder pigs, calves, replacements heifers) and other livestock characteristics (e.g., typical weight and age) were obtained from livestock budgets applicable to Alberta farms as well as FEM defaults that were developed as part of the CEEOT-MMS system (Osei et al. 2003). Defaults in FEM on livestock purchases are based on typical livestock husbandry practices in North America and were used when specific data were unavailable for the RDR study area.

4.2 Manure Management Practices and Nutrient Losses

Information on current manure handling and storage practices, associated nutrient losses, and plant availability of manure nutrients is necessary for performing nutrient BMP evaluations. Manure handling practices and associated nutrient losses are very pertinent for BMP evaluations. For the RDR study, it was assumed that there was minimal manure handling in confinement areas. Due to lack of specific data, it was also assumed that no manure storage losses occurred prior to land application of the manure. Consequently, manure nutrient characteristics obtained from Census data were assumed to reflect manure nutrients available at the time of land applications and no nutrient loss adjustments were applied to the manure nutrient characteristics. However, we realized that after manure application some gaseous N may be lost.

4.3 Equipment Characteristics

Information on farm equipment characteristics that was needed for FEM simulations included field efficiency, economic useful life remaining (in hours), repair and maintenance factors, and remaining (salvage) value factors, among others. Default values of these equipment characteristics were used in the FEM database for a wide range of farm equipment.

4.4 Structures and Facilities Data

Various characteristics of farm structures, buildings, and facilities were used for economic model simulations. These include prices, useful life, and repair and maintenance expenses, among others. Typical farm facilities include livestock and equipment housing, commodity storage barns, earthen structures, and other facilities. Data on these structures were estimated from FEM defaults.

4.5 Wastewater Treatment Discharge Data

The RDR study area included six towns (Olds, Blackfalds, Innisfail, Penhold, Rimbey, and Bashaw) and the City of Red Deer. The wastewater treatment plant discharge data were mainly available from the City of Red Deer from 2000 to 2005 (Table 4.1). The data consisted of monthly values of average daily flow, TSS, NH_3, NO_3, NO_2, and TP discharges. The effluent discharge data from towns were generally incomplete (mainly flow data were available) and these discharges were very low in comparison to the City of Red Deer discharge data. Therefore, for the modelling purposes, only the City of Red Deer effluent data were used to account for contribution of flow and TSS at the main stem of RDR. The TP data were not used because SWAPP only allows input of the organic and soluble fractions of P and these were not available.

4.6 Land Management Data

Actual on-farm land management data were not available within the RDR study area. Collecting such detailed information was beyond the scope of this study. Therefore, for modelling purposes, the detailed field-level information was generated based on the Census data and by interviewing ARD field-staff experts. With this approach, it was possible that the farm management data may not have accurately captured the farm practices such as manure and fertilize application rates, timing and intensity of the farm operations, and livestock stocking rates and grazing management.

4.7 SWAT Input Impoundment Characteristics

Three types of impoundment input parameters were estimated for SWAT: 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 an existing map (Godwin and Martin 1975) that defined the non-stream contributing areas. The

Table 4.1. The estimated average daily effluent discharges from the City of Red Deer wastewater treatment plant from 2000 to 2005.

Month	Flow (m^3 d^{-1})	Total suspended solids (Mg d^{-1})
Jan	30,369	0.45
Feb	30,473	0.34
Mar	33,029	0.37
Apr	33,964	0.37
May	35,733	0.42
Jun	37,141	0.34
Jul	38,086	0.32
Aug	39,698	0.34
Sep	37,255	0.38
Oct	35,939	0.40
Nov	34,665	0.52
Dec	32,487	0.46

coefficient was calculated for each sub-basin by dividing the non-contributing area by the total area and assuming that the runoff from the non-contributing areas was intercepted by wetlands and ponds. The impoundment surface areas were calculated directly from the Landsat imagery data. The storage capacity of impoundments was initially estimated by assuming the maximum average depth was 0.3 m for wetlands. However, this specification was altered based upon model calibration results in order for the wetlands to reflect realistic water, nutrient, and sediment retention for each sub-basin. Some of the ponds were lakes, but they were modelled as ponds since they were not connected directly to main streams. The reservoir (lakes) storage capacities were derived directly from the Atlas of Alberta Lakes (University of Alberta Press 1990). The final SWAPP input values for all impoundment parameters were estimated during the calibration process.

4.8 Simulation Limitations

The RDR study focused primarily on predicting the effects of farm practices on surface water quality and quantity in AESA sub-basins. Less effort was directed to understanding the prediction of natural processes accruing in the remaining RDR sub-basin, major lakes and in the main stem of RDR, and the interaction between the groundwater and surface water.

One of the major limitations of model simulations was generalization of routing sequence of surface flow at the subarea scale and placement of a large wetland right before the outlet of each sub-basin as described in Subsection 2.7. In CEEOT calibration, the specific characteristics of these wetlands were adjusted to reflect flow volumes and sediment and nutrient losses from the respective sub-basin. However, in reality these estimated wetland characteristics perhaps did not capture the actual wetland flow storage effects.

5 SWAPP CALIBRATION

5.1 Calibration Procedure

The main objective of SWAPP calibration was to establish the parameter values for SWAPP (SWAT and APEX) simulations to ensure that the predicted flow rates, TSS, and nutrient export coefficients were in reasonable agreement with the measured values. The SWAT and APEX calibrations were conducted manually using the modelling procedures and instructions provided in the user manuals by Steglich and Williams (2008) and Waidler et al. (2011). The vast majority of the agricultural land in each RDR sub-basin was simulated in APEX. The SWAT model was primarily used to route the APEX predicted flow, TSS, and nutrients through rivers, streams, and reservoirs to the study area 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; Jedrych et al. 2014). Ultimately, the calibration process resulted in establishing values for a set of parameters and assumptions that represented the environmental baseline or calibration baseline scenario.

As mentioned in Sub-section 2.5, water quality and quantity of data were available for SWAPP calibration from a number of monitoring stations in the RDR study area (Table 2.4). However, the content of monitoring data varied among the stations and not all of the data were equally suitable for model calibration. After reviewing the data, only the five AESA water quality monitoring stations (Blindman River, Haynes Creek, Ray Creek, Threehills Creek, and Renwick Creek) and one Water Survey of Canada hydrometric gauging station (05CE001 in Sub-basin 39) were selected for SWAPP calibration.

The calibration of SWAPP for the RDR study area was conducted in two stages. In the first stage, SWAPP calibration was conducted for the RDR study area outlet (Sub-basin 39) using the 1975 to 2005 flow and TSS data available at Station 05CE001. For flow calibration, the 1975 to 2000 period was used as an equilibration period for model simulation, while the 2001 to 2005 SWAPP results were used for assessment of flow prediction in the RDR study area. However for the TSS calibration, the 1975 to 1979 period was used as an equilibration period, and the period from 1980 to 1984 was used for assessing model prediction of TSS. The TSS calibration was conducted only for the 1975 to 1984 period because the TSS data were not available from 1984 to 2005 (Table 2.4). For the calibrations, the equilibration period was deemed necessary for soil conditions and other biophysical properties to reach levels representative of the management practices being simulated. Accordingly, the equilibration period of model output was not included in calibration results or output of model simulations for the scenarios.

The second phase of calibration was conducted by running SWAPP on a daily basis for 2000 to 2005 for the five AESA sub-basins (1, 13, 24, 25, and 32). The pre-2000 and the 2006 AESA data were not used in the calibration because these data did not match the monitoring period of the RDR study area outlet data (Sub-basin 39; Station 05CE001). In the simulations, the first year (2000) was considered as an equilibration period for the model. Similar to the RDR study area calibration, the results for 2001 to 2005 were used for assessing model performance at the sub-basin scale. Once the calibration results from AESA sub-basin simulation were acceptable, the SWAT and APEX parameters adjusted in the calibration process were used to estimate the parameter values for the remaining sub-basins within the RDR study area and ultimately the SWAPP calibrations were conducted for the entire RDR study area.

To calibrate the model in this study, the pre-BMP management conditions were reflected in the model input data. In addition, flow, TSS, and nutrients from the upper portion of the RDR Watershed (i.e., 1,160,000 ha, upstream from Station 05CC002) were entered into SWAPP as point source input data in Sub-basin 17 (Figure 2.4). Also, TSS discharge from the City of Red Deer wastewater treatment plant was entered into the model as point source input data in Sub-basin 16.

It is important to recognize that the drainage areas selected for APEX and SWAPP modelling were almost identical (difference < 1 ha) in the majority of sub-basins. The exceptions were Sub-basins 8, 10, and 16. In these sub-basins, the SWAPP modelling area was larger because these sub-basins included Gull Lake (Sub-basin 8), Buffalo Lake (Sub-basin 10), and the City of Red Deer (Sub-basin 16).

5.2 Evaluation Methods

The mean monthly flow, TSS and nutrient loads and export coefficients obtained from SWAPP calibration were compared to measured values from selected monitoring stations in the RDR study area. 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 obtaining 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 31-yr periods, the monthly calibration was sufficient.

Two statistical methods were used to evaluate the performance of SWAPP. The first statistical method used the correlation of determination (R^2) to evaluate the precision of the regression models to predict flows, TSS, and nutrients. 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 observed values using Equation 5.1.

Equation 5.1

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

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 observed and model predicted values. An *E* value of zero indicates that the model predictions are as accurate as the mean of the observed values. 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 small magnitudes of flow, TSS, and nutrients -at the sub-basin scale.

5.3 Setting Initial Parameter Values

5.3.1 Setting Initial Values for SWAT Parameters

Based on earlier modelling experience (Jedrych et al. 2014), the 16 most sensitive parameters (Table 5.1) were selected for the RDR study area SWAT calibration. These parameters were considered to be sensitive for snowmelt, water balance, and magnitude of surface runoff. During the calibration process, the values of these parameters were allowed to vary while the other SWAT parameters not being calibrated were held constant.

5.3.2 Setting Initial Values for APEX Parameters

The selection of the parameters in Tables 5.2 and 5.3 was also based on the sensitivity of these parameters on the APEX output (Jedrych et al. 2014). The default values of selected parameters from the PARM0604.dat and APEXCONT.dat files were adjusted to match the APEX predicted flow, TSS, and nutrients with measured data. Once a parameter value was established, the value was held constant for all sub-basins in the RDR study area. The parameter values in Table 5.2 were the result of calibration efforts for the RDR study area outlet (Sub-basin 39), and Table 5.3 includes a list of selected parameters for which adjustments were necessary to improve SWAPP prediction in the five AESA sub-basins. During the calibration process, it was discovered that one set of APEX0604 file parameters was not sufficient to obtain good SWAPP calibration results for large and hydrologically diversified watersheds such as the RDR. Therefore, the calibration was refined and improved when some parameters from the PARM0604.dat file were changed for selected AESA sub-basins.

In addition to the parameters in Tables 5.1, 5.2, and 5.3, a number of other parameters were used in APEX and SWAT and were set to default values. No model parameters or routines were excluded from the assessments. It was anticipated the parameter values that resulted from the model calibration efforts were more appropriate than the model defaults for future modelling of other watersheds in Alberta.

The APEX model allows evaluation of groundwater elevation fluctuation on surface runoff. The user has the option of entering the minimum, maximum, and initial water depths, or use model default values. For the RDR study area calibrations, the model default values (minimum = 50 m, maximum = 100 m, and initial = 75 m) were assumed to be appropriate. The default values were considered to be appropriate because the water table within the RDR study area was generally deep (well below the maximum depth of the soil profile) and groundwater likely had little effect on surface runoff.

Table 5.1. List of SWAT sensitive parameters and associated values selected for the Red Deer River study.

Parameter name in SWAT [z]	Description of selected parameters	Values		
		Min.	Max.	Calibrated
SFTMP.bsn	Snowfall temperature (ºC).	-5	5	0.6
SMTMP.bsn	Snowmelt base temperature (ºC).	-5	5	0.5
SMFMX.bsn	Melt factor for snow on June 21 (mm water/ºC-day).	0	10	0.5
SMFMN.bsn	Melt factor for snow on December 21 (mm water/ºC-day).	0	10	0.5
TIMP.bsn	Snow pack temperature lag factor.	0.01	1	0.07
SNOCOVMX.bsn	Minimum snow water content that corresponds to 100% snow cover, SNO100, (mm water).	0	50	36.89
SNO50COV.bsn	Fraction of snow volume represented by SNOCOVMX that corresponds to 50% snow cover.	0.01	0.99	0.9
SURLAG.bsn	Surface runoff lag coefficient.	1	12	1
ESCO.bsn	Soil evaporation compensation factor.	0.01	1	0.67
EPCO.bsn	Plant uptake compensation factor.	0.01	1	0.89
GW_REVAP.gw	Groundwater “revap” coefficient.	0.02	0.2	0.02
GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm water).	0	5000	0
ALPHA_BF.gw	Baseflow alpha factor (days).	0	1	0.048
GW_DELAY.gw	Groundwater delay time (days).	0	500	31
REVAPMN.gw	Threshold depth of water in the shallow aquifer for “revap” or percolation to the deep aquifer to occur (mm water).	0	500	1
RCHRG_DP.gw	Deep aquifer percolation fraction.	0	1	0.05

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

Table 5.2. List of APEX sensitive parameters and associated values selected for the Red Deer River study.

		Acceptable values		
Parameter description		Min.	Max.	Calibrated
PARM (n)	*APEX PARM0604.dat file*			
4	Water storage N leaching	0	1	0.7
8	Soluble phosphorus runoff coefficient. (0.1 m^3 Mg^{-1})	10	20	12
14	Nitrate leaching ratio	0.1	1	0.12
15	Runoff CN weighting factor	0.0	1.0	1
16	Expands CN retention parameter	1.0	1.5	1
17	Soil evaporation - plant cover factor	0.0	0.5	0.5
18	Sediment routing exponent	1	1.5	1
19	Sediment routing coefficient (Mg m^{-3})	0.01	0.05	0.05
20	Runoff curve number initial abstraction	0.05	0.4	0.30
22	Runoff CN retention parameter for frozen soil	0.05	0.5	0.2
25	Exponential coefficient for rainfall intensity on CN	0.0	2.0	0
30	Soluble phosphorus runoff exponent	1	1.5	1.4
32	Organic N and P sediment transport exponent	1	1.2	1
40	Groundwater storage threshold	0.001	1.0	0.1
42	SCS curve number index coefficient	0.5	1.5	1
44	Upper limit of CN retention parameter	1.0	2.0	1
45	Sediment routing travel time coefficient	0.5	10	5
46	RUSLE C - factor coefficient	0.5	1.5	0.7
47	RUSLE C - factor coefficient	0.5	1.5	1
49	Maximum rainfall interception by plant canopy (mm)	2.0	15	2
50	Rainfall interception coefficient	0.05	0.3	0.3
61	Soil water tension weighting factor	0.0	1.0	0.8
62	Manure erosion equation coefficient	0.1	0.5	0.1
68	Manure erosion exponent	0.1	1.0	0.1
69	Manure erosion coefficient	1.0	1.5	1
72	Volatilization/nitrification partitioning coefficient	0.05	0.5	0.5
74	Nitrate leaching ratio for lateral return flow	0.01	0.05	0.04
80	Soil radiation threshold for snowmelt	10	20	20
Variable (n)	*APEX APEXCONT.dat file*			
GWSO	Maximum groundwater storage	5	200	100
RFTO	Groundwater residence time in days	0	365	30
RFPO	Return flow	0	1.0	0.3
IET	Potential evapotranspiration equation code		B.-R.[z]	
DRV	Soil loss equation		RUSLE2[y]	

[z] B.-R.: Baier-Robertson equation selected.

[y] RUSLE2: Modified revised universal soil loss equation selected.

Table 5.3. List of APEX sensitive parameters and values estimated as a result of APEX calibration for the selected Alberta Environmentally Sustainable Agriculture Project sub-basins in the Red Deer River (RDR) study area.

PARM (n)	APEX PARM0604.dat file parameter description	Acceptable Values		Calibrated values for selected RDR sub-basins				
		Min.	Max.	1	13	24	25	32
4	Water storage N leaching	0	1	0.1	0.7	0.7	0.7	0.7
8	Soluble phosphorus runoff coefficient (0.1 m^3 Mg^{-1})	10	20	20	12	20	20	12
14	Nitrate leaching ratio for surface runoff	0.1	1	0.12	0.20	0.11	0.12	0.12
20	Runoff curve number initial abstraction	0.05	0.4	0.20	0.20	0.10	0.20	0.30
42	SCS curve number index coefficient	0.5	1.5	1.50	1.50	1.50	1.30	1.00
47	RUSLE C-factor crop height coefficient	0.5	1.5	1.00	1.00	0.70	1.00	1.00
49	Maximum rainfall interception by plant canopy (mm)	2.0	15	2.0	2.0	5.0	2.0	2.0

5.4 Calibration Results and Discussion

Model results from two calibration periods (1980 to 1984 and 2001 to 2005) were used for SWAPP evaluation at the RDR study area outlet (Sub-basin 39). An additional 1980 to 1984 period was selected because the TSS data were not available from 2001 to 2005 (Table 2.4). The comparison between monthly simulated and observed flow and TSS data (Figure 5.1; Table 5.4) showed very close correlation. The estimated R^2 and *E* values for predicted flow were 0.96 and 0.93, respectively. These high R^2 and *E* values were expected because, as mention above, the majority of flow input data were generated based on the measurement at the upstream portion of RDR Watershed (Station 05CC002; Table 2.4) and it was entered into the model as a point source. Therefore, the SWAPP-predicted increase in flow downstream from Station 05CC002 was relatively small (13%) when compared to the total amount of flow measured at Stations 05CC002 (upstream) and 05CE001 (downstream). Contrary to the small difference in flow yields between these two stations, there was a large (365%) increase of TSS load at Station 05CE001. This SWAPP prediction was relatively satisfactory with R^2 and *E* values of 0.73 and 0.72, respectively. Moreover, SWAPP prediction of nutrients was not calibrated at the RDR study area outlet (Sub-basin 39) because there was no measured nutrient data available at Station 05CE001.

The monthly simulated and observed environmental indicators (flow, TSS, and nutrients) were in good agreement at the outlet of the AESA sub-basins (Table 5.4). The R^2 values ranged from 0.36 to 0.94 and *E* values ranged from 0.26 to 0.93, and the majority of these value were higher than 0.60. The only exceptions were prediction of ON in Sub-basins 13 and 24, and predictions of OP in Sub-basins 24, 25, and 32 for which the *E* values ranged from 0.26 to 0.42. In these sub-basins, the observed and predicted TSS and nutrient export coefficients had very low values (Appendix 2; Figures A2.2, A2.3, and A2.5). For example, in Sub-basin 24, the maximum TSS, TN, and TP measured export coefficients were 0.0002 Mg ha^{-1}, 0.088 kg ha^{-1}, and 0.018 kg ha^{-1} during the 2001 to 2005 period, respectively. The low R^2 and *E* values in these sub-basins suggest that less satisfactory model performance can be attributed to very low observed TSS and nutrient values and the limitation of SWAPP to predict accurately at this scale.

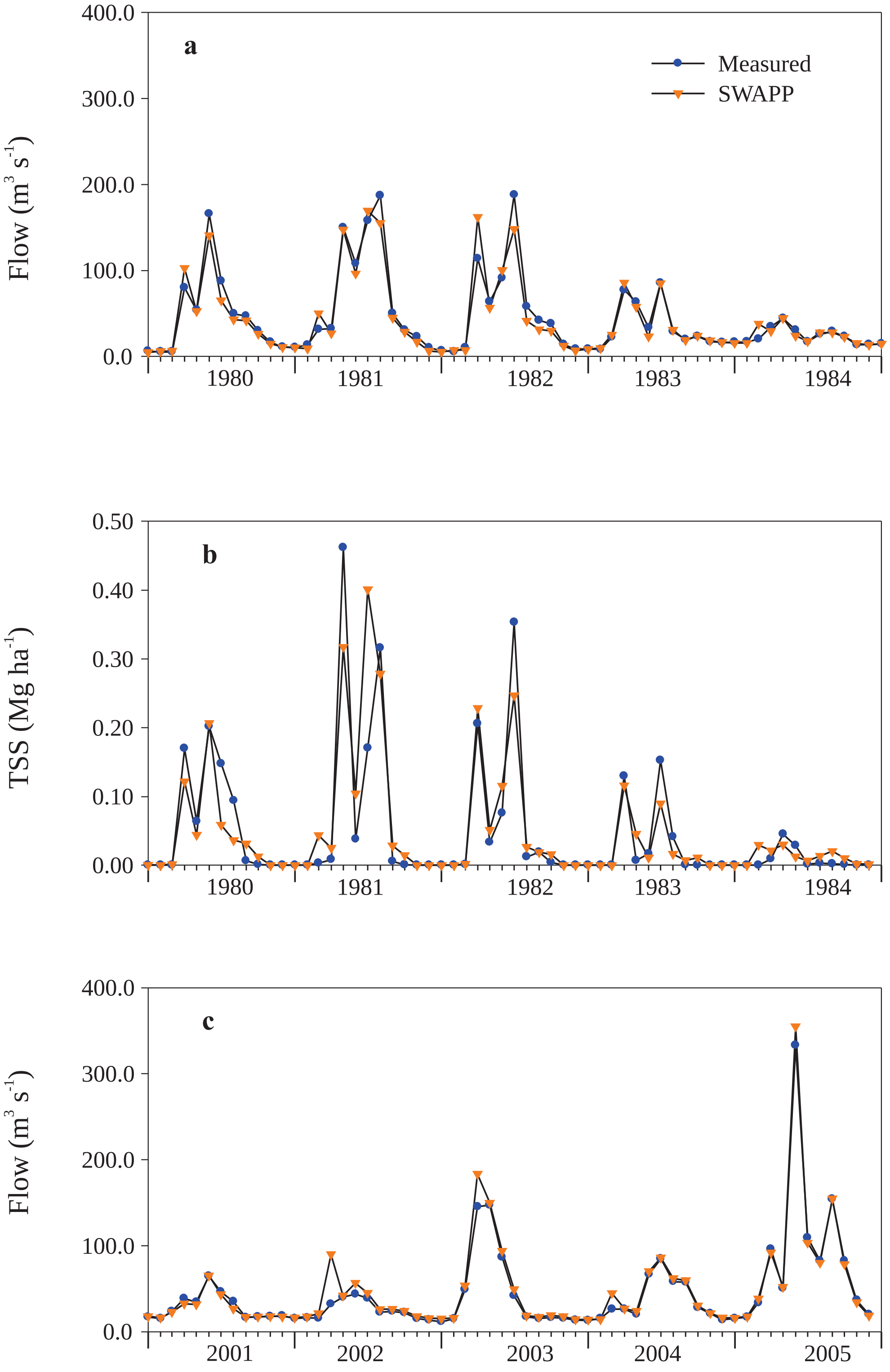

Figure 5.1. Measured and predicted SWAPP mean monthly flow and total suspended solids (TSS) export coefficient from 1980 to 1984 and for flow from 2001 to 2005 at the RDR study area outlet (Station 05CE001; Sub-basin 39).

Table 5.4. Summary of R^2 and *E* values for flow, total suspended solids (TSS), and nutrients from SWAPP calibration for selected Alberta Environmentally Sustainable Agriculture sub-basins (1, 13, 24, 25, and 32) and Red Deer River study area outlet (Sub-basin 39).

Sub-	Flow		TSS		Nitrate N		Phosphate P		Organic N		Organic P		Total N		Total P	
basin	R^2	*E*	R^2	*E*	R^2	*E*	R^2	*E*	R^2	*E*	R^2	*E*	R^2	*E*	R^2	*E*
							2001 to 2005 calibration results									
1	0.77	0.74	0.71	0.70	0.58	0.54	0.53	0.44	0.69	0.62	0.70	0.66	0.69	0.62	0.62	0.60
13	0.72	0.68	0.66	0.53	0.88	0.87	0.65	0.57	0.51	0.41	0.60	0.53	0.59	0.52	0.64	0.55
24	0.79	0.78	0.63	0.58	0.79	0.67	0.69	0.68	0.50	0.40	0.61	0.28	0.58	0.51	0.66	0.64
25	0.91	0.91	0.79	0.77	0.72	0.71	0.73	0.63	0.81	0.79	0.69	0.42	0.80	0.78	0.74	0.60
32	0.77	0.70	0.87	0.86	0.94	0.93	0.72	0.56	0.62	0.56	0.36	0.26	0.77	0.72	0.69	0.53
39	0.93	0.88	na	na	na	na	na	na	na	na	na	na	na	na	na	na
							1980 to 1984 calibration results									
39	0.96	0.93	0.73	0.72	na[z]	na	na	na	na	na	na	na	na	na	na	na

[z] na = not available.

The predicted and observed environmental indicator values among the AESA sub-basins showed that SWAPP underestimated on average flow by 18%, ON by 45%, OP by 49%, PO_4-P by 29%, TN by 38%, and TP by 36% during the 5-yr period (2001 to 2005). However, during the same period, the model overestimated the total amount of TSS by 1% and NO_3-N by 11% (Table 5.5). It is interesting to note that under predictions of flow in Sub-basins 13 and 24 were not consistent with overestimation of TSS and NO_3-N loss. Generally, we would expect that model underestimation of flow would also result in an underestimation of TSS and nutrient losses. However, this assumption was not true for Sub-basins 13 and 24. This may further confirm the limitation of SWAPP to predict accurately TSS and nutrient values at very low flows, as mentioned previously.

Also, it is important to note that the prediction accuracy of SWAPP was affected by the limitation of model input data. In particular, there was a lack of input data on the subarea-routing sequence used in APEX. An earlier study by Jedrych et al. (2014) showed that the hydrological routing sequence is pertinent for a correct prediction of environmental indicators. However, in the RDR study, the routing sequence was generalized and perhaps did not represent the actual routing conditions. In addition, the land management data used in the calibration were derived from the 2001 Census data, which perhaps did not fully represent actual farm practices during the 2001 to 2005 calibration period.

Table 5.5. Estimated percent differences between the cumulative measured and predicted environmental indicators among the Alberta Environmental Sustainable Agriculture sub-basins for the 2001 to 2005 calibration period.[z]

Sub-basin ID	Flow	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	(%)							
1	-30	-9	-44	-30	-6	1	-42	-12
13	-2	54	-52	-27	27	-30	-42	-37
24	-24	9	-52	-61	63	-14	-41	-23
25	-15	-26	-33	-65	-20	-44	-31	-48
32	-20	-24	-45	-62	-12	-58	-35	-59
Average	-18	1	-45	-49	11	-29	-38	-36

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Negative percent values indicate SWAPP underestimation.

6 FEM CALIBRATION

Compared to the APEX and SWAT models, the FEM model data were readily available at the provincial level, and as a result, less calibration was required for FEM. Thus, the FEM model calibrations performed for the initial CEEOT application in Alberta (Jedrych et al. 2014) were used for the FEM simulations of the RDR study area.

FEM calibrations normally focus on the following output measures:

- Costs of field operations
    - Variable and fixed costs per hectare and per hour
- Livestock feed costs
    - Total feed cost per head and per animal unit
    - Percent of key nutrients (protein, calcium, phosphorus, etc.) and energy per unit of daily dry-matter intake
- Farm profits, total revenue, and total cost

Numerous boundary conditions were included in FEM for livestock feed ration determination. The following were the categories of parameter boundaries used in the model for each type of livestock:

- Total dry matter intake – requirement and upper bound
- Requirement and upper bound for all nutrients
- Percentage of each feed type purchased and fed (lower and upper boundary constraints)
- Percentage of each feed type raised on-farm and fed to livestock

7 BMP SCENARIO MODELLING

7.1 Development of Scenarios for Modelling

In total, seven BMP simulation scenarios were developed based on consultation with the team leads of the BMP Project (Table 7.1). Each scenario consisted of a combination of specific practices or policies that were not necessarily evenly applicable to all land-use parcels within each sub-basin. These scenarios included a number of practices that were considered to be relevant for the RDR study area and addressed the following concerns: (a) manure management, (b) grazing management, (c) seasonal bedding, (d) erosion control, (e) riparian management, and (f) wetland restoration. Scenario 1 was the baseline scenario, which represented the status quo without additional BMPs as explained below. Scenarios 2 to 7 built upon Scenario 1 and each scenario had a unique number of BMPs that were relevant to the scenario and targeted specific concerns of the study area (Table 7.1). The scenario simulations were conducted for a 31-yr period using climate data from 1995 to 2005.

7.1.1 Scenario 1: Baseline

The baseline (status quo) scenario assumed that all producers were in compliance with the Alberta Agricultural Operation Practices Act (AOPA) regulations prior to the simulation of additional 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

Table 7.1. List of scenarios and associated beneficial management practices used for CEEOT model simulations for the Red Deer River study area.[z]

	Beneficial management practices								
Scenarios	P limit - crop removal rate	N inorganic limit - crop removal rate	Rotational grazing	Cattle restriction from water bodies	Excluding cattle from riparian areas in winter months	Minimum 100-m setbacks away from waterways	15-m grassed waterways	15-m buffer strips	Restore previously drained wetlands
1. Baseline	Producers are in compliance with the AOPA[y] regulations								
2. Manure management	X	X							
3. Rotational grazing			X	X					
4. Seasonal bedding					X	X			
5. Grassed waterways							X		
6. Riparian setbacks								X	
7. Wetland restoration									X

[z] More detail descriptions of the land-use management practices are in Sub-sections 7.1.1 through 7.1.7.

[y] AOPA = Alberta Agricultural Operation Practices Act.

management data (Sub-section 2.3). The main differences between these two datasets were in the simulation duration and associated inputs of land management and climate data. The following is a list of AOPA specifications as simulated in the modelling system:

- **Manure application based on nitrate nitrogen concentration in the top 60 cm of soil.** 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 7.2). 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 predicated 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.
- **Manure incorporation within 48 hours of application.** The AOPA specifies that manure applied (liquid or solid) on cultivated fields must be incorporated within 48 h after application. 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 right after or during application. In FEM, an additional tillage operation was used within 48 h if no tillage operation followed the manure application.
- **No winter application (i.e., snow covered or frozen soil).** Restrict manure application to the periods of April to June and September to November. To simulate this AOPA feature, the CEEOT application has the capability of scanning all the APEX management files programmatically to determine timing of manure applications. Any manure applications scheduled for December through March would then be rescheduled to the April to June period prior to simulation of the modelling system. However, in the current project, all nutrient applications were initially assigned within the spring and summer months; hence, there were no manure timing adjustments made to the management files.
- **Setbacks for manure application.** Setbacks from common bodies of water are required for forage or direct seeded fields that receive manure. In AOPA, the width of the setback area depends on the slope of the field (Table 7.3). 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

Table 7.2. Soil nitrate nitrogen (NO_3-N) limits in the top 60 cm of soil in the Alberta Agricultural Operation Practices Act for fields receiving manure (Province of Alberta 2010).

	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})	--------------------------------
Brown	80	110	140
Dark Brown	110	140	170
Black	140	170	225
Gray Luvisol	110	140	170
Irrigated	180	225	270

Table 7.3. Manure application setback widths under Alberta Agricultural Operation Practices regulations (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

setback. On the setback areas, manure applications were eliminated, and although not required by AOPA, the simulation assumed supplemental fertilizer applications for maintaining crop production potential. The modelling of setbacks applied to many fields, as many common bodies of ephemeral water existed.

7.1.2 Scenario 2: Manure Agronomic Phosphorus Management

For Scenario 2, manure application was based on agronomic P requirements, or the P crop removal rate, and it was prioritized based on the type of simulated crop rotations (Table 7.4). In the scenario, it is expected that soil-test phosphorus (STP) will not change since the amount of P added should match the amount of P removed by the crop. In addition, it was assumed that:

- When the P limit guideline does not allow manure application, the manure was applied to adjacent sub-basins before being transported out of the study area. Furthermore, in model simulations it was assumed that manure would be applied on adjacent lands in the sub-basins where the manure was generated prior to transporting the manure to other sub-basins within the RDR study area.
- Inorganic N may be applied if manure N supplied was below crop requirement levels.

Simulation of Scenario 2 in the environmental module of CEEOT entailed dynamic modifications of the management files in order to capture the manure transfers required. The following procedure was programmed to generate management files that were consistent with the requirements of Scenario 2.

Table 7.4. Order of crop rotations used for prioritizing manure application in Scenario 2.

Type of crop rotation and land cover	Priority rank	Portion of subarea
SWHT - BARL - BARL - CANA[z]	1	1
SWHT - CANA - BARL - CANA	1	1
SWHT - BARL - SWHT - BARL - CANA	1	1
SWHT - SWHT - CANA - OATS	2	1
SWHT - BARL - CANA - OATS	2	1
BARL - BARL - CANA - OATS	2	1
BARL - BARL - ALFA - ALFA - ALFA - ALFA	3	1
BARL - SWHT - ALFA - ALFA - ALFA - ALFA	3	1
CANA - SWHT - BARL - AGRL	4	0.75
FPEA - BARL - CANA - BARL	4	1
BARL - BARL - AGRL	5	0.67
SWHT - SWHT -AGRL	5	0.67
HAY	6	1
Tame pasture	7	1
Native pasture	8	1
FRSD	9	0

[z] Crop abbreviations: SWHT = spring wheat, BARL = barley, CANA = canola, ALFA = alfalfa hay, FPEA = field peas, HAY = grass hay, FRSD = forest deciduous, AGRL = fallow.

First, the total manure generated within each sub-basin was calculated using the Census data. This value represented annual manure production levels and the associated manure N and P production levels. Since the livestock inventory was assumed equal to the Census values and only one year of Census data was used, livestock inventory, and hence, manure and manure nutrient production levels, were assumed constant from year to year. Second, crop agronomic N and P requirements were calculated for each year of the 31-yr simulation period for each subarea using the crop rotation data for that subarea.

Manure was applied on crops in each rotation based on the priority order of crop rotations listed in Table 7.4. Beginning in year one, manure was applied based on the P agronomic requirement of the crop grown in that year. A random order of subareas with the highest priority cropping system in that sub-basin received manure at the P agronomic uptake rate. Then manure was applied to the next priority crop for that year if some manure nutrients remained. After all manure was used up, the remaining subareas received no manure pending manure availability from other sub-basins. If all subareas received manure, then the manure nutrient balance (i.e., any remaining manure nutrients) was stored pending any manure transfers dictated by manure balances of other sub-basins.

This manure application procedure was used in all sub-basins for a given year. Once all sub-basins had been addressed for a given year, sub-basins with manure P deficits received manure from sub-basins with manure P surpluses. To determine which sub-basins exported manure and which sub-basins received manure, a priority table (Table 7.5) was developed. Priority was based on the sub-basin delineation map that showed the proximity of sub-basins to each other, and consequently the priority order of manure transfers among the sub-basins.

Once all manure transfers had been completed for the year in question, any subareas that did not receive manure or received insufficient manure were assigned the appropriate inorganic P fertilizer to bring total nutrient applications to each crop to the agronomic uptake rates. Once all P nutrient requirements had been satisfied for that year, crop N requirements were then addressed using supplemental inorganic N fertilizer as required.

The manure nutrient application and transfer procedure described above was repeated for each year of the simulation horizon. Consequently, manure transfers would vary among years due to changes in crop cover and hence nutrient requirements from year to year. The average annual sub-basin manure nutrient and inorganic nutrient application rates are shown in Table 7.6. Readers should note that these are the average rates used and include no manure application as required from year to year based on AOPA soil NO_3-N considerations.

The economic model used in this study, FEM, already had the capability of dynamic manure transfers from the source farm to other areas. Furthermore, it automatically applies supplemental nutrient levels as needed. Thus, it generates cost and returns data that include all the manure hauling, spreading, application, and supplemental fertilizer use considerations needed for this scenario. However, FEM does not provide the spatial capabilities of identifying how farm manure is hauled from a given farm. For this reason, typical hauling distances were calculated from the procedure described above for the environmental module and used as input into the FEM simulations.

7.1.3 Scenario 3: Rotational Grazing and Controlled Access

In Scenario 3, rotational grazing was simulated on all grazed pastures. Open-access grazing was assumed for the baseline scenario. Rotational grazing is the practice of moving cattle from pasture to pasture in a scheduled fashion in order to improve pasture conditions during the grazing season when pastures are more sensitive (spring and early summer) to degradation by cattle access. In the simulation, each pasture field was divided into four subareas. Two of these subareas (95% of total pasture area) were dedicated for rotational grazing, one subarea (2.5% of total area) was devoted for filter strip, and the remaining subarea (2.5% of total area) was used for cattle bedding. The pasture fields in Scenarios 1 and 3 were configured so that surface runoff from the grazing subareas run into filter and bedding subareas, respectively. In addition, the rotational grazing effects were simulated by improving the curve number of grazed subareas where this feature applied, in comparison to the baseline scenario where open access, unmanaged grazing occurred.

Table 7.5. The priority order of manure transfers among adjacent sub-basins

Sub-basin ID	Area to receive manure (ha)	The priority order for selected sub-basins									
		A	B	C	D	E	F	G	H	I	J
1	8,018	2	5	8	12	9	20	17	16	19	25
2	6,720	1	5	8	12	9	20	17	16	19	25
3	2,939	4	11	6	13	14	18	20	10	26	23
4	1,300	3	11	6	13	14	10	18	20	26	23
5	27,663	1	2	12	8	9	20	17	16	19	18
6	17,245	7	11	14	10	26	13	18	4	3	15
7	738	6	10	26	11	14	13	4	3	15	18
8	9,026	9	2	5	12	20	17	16	1	19	18
9	216	8	12	5	20	17	16	2	1	18	23
10	36,785	7	6	26	15	11	14	18	4	3	13
11	16,592	4	6	14	13	3	7	10	18	20	26
12	28,792	9	5	20	8	17	16	19	2	18	13
13	15,344	14	18	11	20	6	4	16	3	10	26
14	10,473	13	11	6	26	18	20	10	7	4	15
15	18,598	21	26	10	27	22	14	6	18	30	33
16	3,340	17	20	19	12	18	23	9	25	24	13
17	3,100	16	20	19	12	8	23	25	18	9	34
18	27,090	26	30	28	23	20	13	4	16	19	11
19	27,265	17	16	20	23	25	24	34	18	29	12
20	14,927	18	19	12	16	17	23	25	13	11	14
21	7,397	22	27	15	26	10	14	18	30	33	6
22	1,500	27	21	15	26	33	10	30	14	6	28
23	6,040	18	28	25	19	20	29	24	30	16	34
24	3,487	24	25	29	34	19	23	28	31	18	36
25	10,171	23	19	24	29	28	34	20	18	31	16
26	36,527	10	15	27	30	18	14	6	33	21	28
27	25,119	26	33	15	22	21	30	37	18	28	14
28	17,191	30	37	29	23	31	18	25	33	36	26
29	14,448	28	31	34	24	25	23	36	19	36	30
30	13,823	26	33	28	18	37	23	27	15	29	25
31	3,182	29	28	36	37	34	32	25	24	23	30
32	5,666	36	34	31	37	41	35	28	29	33	25
33	20,901	37	38	30	27	26	28	39	36	31	40
34	37,227	35	29	36	41	32	24	19	25	28	23
35	68,833	34	41	36	32	31	29	24	19	25	37
36	51,103	32	37	41	34	31	28	29	38	33	35
37	33,331	36	33	38	28	41	40	31	30	39	32
38	10,450	37	33	39	40	41	36	32	27	30	31
39	5,025	38	40	37	41	36	33	32	35	34	31
40	5,844	41	39	38	37	36	33	35	34	32	31
41	59,090	36	35	37	40	34	32	38	39	33	31

Table 7.6. Average manure nutrient and inorganic fertilizer nutrient application rates.

	Based on crop N requirements estimated for Baseline and Scenarios 3 to 7			Based on crop P requirements estimated for Scenario 2		
Sub-basin ID	Manure[z]	N fertilizer	P fertilizer	Manure[z]	N fertilizer	P fertilizer
	(kg ha^{-1})					
1	3,209	40.9	12.3	3,668	16.9	0.0
2	6,155	33.3	9.5	3,893	20.5	0.5
3	19,050	12.7	0.1	943	33.4	0.1
4	15,583	9.3	0.2	328	25.9	0.2
5	13,953	28.8	5.7	2,631	33.1	0.8
6	4,964	56.6	10.0	5,050	32.8	0.5
7	9,861	46.5	1.7	8,056	40.4	1.7
8	8,555	30.4	6.6	4,437	28.3	0.9
9	18,732	14.4	0.3	144	37.7	0.3
10	3,745	68.7	10.7	6,066	35.1	0.5
11	9,830	39.4	7.6	5,405	34.9	0.4
12	13,811	36.0	6.1	2,908	37.4	0.7
13	3,415	110.3	9.5	6,322	42.3	0.6
14	10,923	42.1	0.4	1,171	39.0	0.4
15	7,270	58.5	0.2	640	33.4	0.2
16	8,543	54.0	1.0	418	48.2	1.0
17	14,102	31.2	1.7	259	42.2	1.7
18	9,702	34.6	1.0	2,865	34.8	1.0
19	7,228	64.0	8.3	4,719	43.1	1.3
20	10,307	45.3	1.0	1,668	41.1	1.0
21	8,351	52.8	0.9	856	32.5	0.9
22	7,196	48.5	1.2	171	33.6	1.2
23	7,427	32.2	0.3	1,070	22.4	0.3
24	1,035	73.3	9.5	6,100	43.2	2.7
25	7,345	62.3	14.4	5,715	39.8	0.9
26	7,370	60.3	0.4	1,300	34.4	0.4
27	6,352	46.0	0.4	825	29.3	0.4
28	3,465	79.7	13.5	4,625	41.8	0.9
29	2207	87.7	12.2	5,029	46.9	2.6
30	6488	55.9	1.3	469	34.8	1.3
31	1,319	91.4	21.1	8,412	46.4	2.0
32	878	90.5	6.8	6,664	43.9	1.7
33	4,841	61.4	3.1	671	42.7	3.1
34	2,962	83.9	15.3	6,195	41.4	0.9
35	5,318	60.0	7.7	5,989	39.3	0.3
36	1,786	71.5	7.6	6,092	45.0	1.3
37	4,162	56.7	0.8	1,330	47.7	0.8
38	2,458	41.7	3.3	321	43.0	3.3
39	2,727	42.8	3.5	151	42.7	3.5
40	6,153	24.2	1.0	604	41.3	1.0
41	4,071	61.5	12.5	4,954	42.7	2.1

[z] Dry-weight mass.

Numerous studies indicate clearly that rotational grazing results in improved pasture vegetative cover and forage yield (Loeffler et al. 1996; Winsten and Petrucci 1996; Undersander et al. 1993). In a previous study on dairy grazing systems in the Lake Fork Reservoir watershed in Texas, McNitt et al. (1999) estimated that intensive grazing systems would result in more than double the forage production of open access grazing systems, partly due to improved vegetative cover, but also partly due to increased nutrient applications. The current study assumes a more conservative approach where pasture forage under rotational grazing is only 20% higher than under open access grazing, with no changes in fertilizer nutrient applications. The rotational grazing simulations also assumed that additional labour costs would be incurred annually and a one-time fencing capital outlay would also be necessary in order to move cattle from one paddock to another.

7.1.4 Scenario 4: Seasonal Bedding and Feeding Sites

In Scenario 4, two BMPs were modelled to reduce environmental impacts from cattle bedding and feeding sites near waterways. The BMPs were:

- Excluding cattle from riparian areas in winter months
- Establishing site setbacks at a minimum of 100 m away from waterways

In Scenario 4 simulations, the pasture fields were also divided into four subareas similarly as described for Scenario 3, but there was no rotational grazing and the subarea configuration assumed that water flows from grazing subareas into cattle bedding sites and then into filter strips. To ensure the 100-m setback, a fence was installed to restrict cattle access to streams in winter months. This was a one-time cost and the fence was assumed to have an economic life of about 30 yr with minimal maintenance. Additional labour costs were also assumed to be incurred and the total cost of establishing the seasonal bedding area averaged \$136 ha^{-1} yr^{-1} in this scenario.

7.1.5 Scenario 5: Grassed Waterways

Scenario 5 involved the application of 15-m wide grassed waterways in the middle of grain/oilseed production fields (subareas). For this scenario, it was assumed that all runoff from the upland area of the field flowed through the waterway prior to leaving the field. Also, it was assumed that grassed waterways were only necessary on the subareas where the TSS losses, derived from APEX simulation in Scenario 1, were equal or greater than the 85th percentile of all predicted values. Based on this assumption, grassed waterways were implemented in 15 of the 41 sub-basins and accounted for 423.3 ha (0.03 %) of the total RDR study area (Table 7.7).

Table 7.7. Area extent of grassed waterways, riparian setbacks, and wetlands implemented in the Red Deer River study area in Scenario 5, 6, and 7, respectively.

Sub-basin ID	Sub-basin area (ha)	Grassed Waterway		Riparian Setback		Wetland	
		(ha)	(%)[z]	(ha)	(%)	(ha)	(%)
1	35,393.8	0.0	0.00	11.9	0.03	181.6	0.51
2	25,323.4	35.1	0.14	15.2	0.06	196.6	0.78
3	7,049.2	0.0	0.00	10.9	0.15	11.9	0.17
4	3,117.5	0.0	0.00	0.0	0.00	0.0	0.00
5	43,230.2	48.5	0.11	18.0	0.04	127.8	0.30
6	31,059.6	0.0	0.00	29.2	0.09	183.4	0.59
7	1,329.0	0.0	0.00	3.6	0.27	0.0	0.00
8	29,263.2	32.5	0.11	34.0	0.12	151.0	0.52
9	707.6	0.0	0.00	0.0	0.00	0.0	0.00
10	72,691.0	0.0	0.00	136.1	0.19	662.9	0.91
11	39,793.9	0.0	0.00	25.2	0.06	53.9	0.14
12	44,767.7	19.7	0.04	21.0	0.05	40.1	0.09
13	17,445.1	47.5	0.27	15.4	0.09	9.4	0.05
14	20,514.2	2.7	0.01	16.8	0.08	61.2	0.30
15	33,842.2	0.0	0.00	55.6	0.16	181.0	0.53
16	6,541.4	0.0	0.00	3.9	0.06	12.4	0.19
17	4,728.8	0.0	0.00	11.6	0.25	0.0	0.00
18	53,061.9	0.0	0.00	67.3	0.13	150.8	0.28
19	35,641.3	0.0	0.00	36.6	0.10	0.0	0.00
20	29,237.5	0.0	0.00	48.8	0.17	19.5	0.07
21	13,177.3	0.0	0.00	27.0	0.20	125.3	0.95
22	2,672.8	0.0	0.00	17.0	0.64	17.8	0.67
23	13,496.1	0.0	0.00	15.3	0.11	26.5	0.20
24	4,522.9	23.3	0.52	7.4	0.16	0.0	0.00
25	15,379.2	41.1	0.27	20.1	0.13	0.0	0.00
26	66,467.7	0.0	0.00	76.8	0.12	272.2	0.41
27	45,708.3	6.4	0.01	56.4	0.12	378.0	0.83
28	38,123.1	0.0	0.00	37.7	0.10	130.3	0.34
29	17,446.2	0.0	0.00	26.8	0.15	55.9	0.32
30	25,153.2	0.0	0.00	61.5	0.24	134.2	0.53
31	9,073.4	0.0	0.00	7.1	0.08	14.6	0.16
32	5,796.3	0.0	0.00	0.0	0.00	0.0	0.00
33	38,032.4	28.9	0.08	48.6	0.13	54.7	0.14
34	65,215.1	19.4	0.03	36.6	0.06	57.3	0.09
35	87,267.9	0.0	0.00	35.8	0.04	146.5	0.17
36	55,236.5	0.0	0.00	16.4	0.03	124.2	0.22
37	60,650.4	92.7	0.15	24.4	0.04	206.7	0.34
38	19,016.0	7.2	0.04	23.9	0.13	86.6	0.46
39	9,143.7	5.9	0.06	9.6	0.10	29.2	0.32
40	9,817.5	0.0	0.00	9.4	0.10	9.6	0.10
41	81,397.2	12.4	0.02	44.3	0.05	158.7	0.19
Total	1,217,531.3	423.3	0.03	1163.0	0.10	4071.7	0.33

[z] Percentage of the total RDR study area.

7.1.6 Scenario 6: Riparian Setbacks

In Scenario 6, riparian setbacks were modelled in subareas that were adjacent to streams. The purpose of a riparian setback was primarily to filter TSS and reduce runoff velocity and edge-of-field erosion. In the simulations, buffer strip width was set at 15 m and consisted of perennial pasture vegetation. In the RDR study area, 38 sub-basins (1163.0 ha area) was selected for riparian setback implementation (Table 7.7). The application of setbacks involved the following management practices:

- No manure or fertilizer application, no cropping activity, and no access by livestock
- No agricultural production within the setback:
    - cropland in grain/oilseed production was seeded to grass
    - cropland in forage was not harvested
    - existing pastures required installation of a fence and no grazing was permitted

7.1.7 Scenario 7: Wetland Restoration

Scenario 7 involved restoration of previously drained wetland. The extent of wetland restoration in Scenario 7 was estimated based on the difference of wetland area between the 2000 and 2011 Landsat imagery. Based on the available data, it was estimated that 4071.7 ha of wetland area was reduced during the 11-yr period within the RDR study area and therefore 4071.7 ha area was selected for wetland restoration in Scenario 7 (Table 7.7).

Wetland restoration was simulated by creating a minimum 30-m wide subarea along the edge of the field with perennial cover such as pasture, rangeland, forest, and along the borders of the existing 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 surface flow from the upland area routed through the wetland prior to leaving the field.

7.2 Modelling Assumptions, Specifications, and Limitations

Once CEEOT calibration was completed, the initial values of model parameters and coefficients were established for the RDR study area for the baseline and 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 the RDR study area 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 31 yr (1975 to 2005) of climate data available from the nearest weather stations instead of 6, 10, or 30 yr used in model calibration.

Manure incorporation. To simulate this management practice, two main options were used in CEEOT. The first option was to specify a nutrient application depth in the APEX model (i.e., in the operation file). The second option was 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 allow us to use the second option as well, by specifying that option when running simulations. A 7.62-cm (3 inch) depth was assumed for the manure incorporation scenario.

One assumption implicit for all of the BMP scenarios was that any manure generated on-farm but not applied within that farm was applied to adjacent lands within the sub-basin. If there was not sufficient land available, then the manure was transported to land within adjacent sub-basins. In particular, for Scenario 2, in which manure applications were based on the P uptake rate of crops, the economic implications of hauling manure to adjacent lands were included in the evaluation.

Manure setbacks. Manure setbacks were simulated in the environmental and economic models as separate areas removed from the crop (parent) fields. Based on model specifications assumed for the scenarios, these setbacks did not receive manure. Instead, setback areas received inorganic fertilizer and 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 individual field, and a square configuration served 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.

Soil nitrate nitrogen limits on manured fields. 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 7.2). 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.

7.3 Simulation Procedures and Interpretation of Results

The results presented below are annual averages of 31-yr simulation horizons. Specifically, the impacts presented were computed as follows. First, the average annual runoff depth (mm) and the TSS export coefficients (Mg ha^{-1}) and nutrient export coefficients (kg ha^{-1}) at the outlet of each of the sub-basin were calculated by taking the average of all 31 annual SWAPP output values for each environmental indicator. Annual average runoff depth and export coefficients were computed for all seven scenarios: the baseline and the six 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 31-yr simulation output from FEM for each farm. Then the farm-level annual averages were summed using all farms in the study area to obtain study area level annual averages. In this step, the study area level averages were computed using the number of farms each representative farm represented as a weighting factor. 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 net farm returns and the corresponding per hectare net farm returns 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 this is 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 study area 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 study area. Scenario impacts are presented at the sub-basin level in more detail in Appendix 3. 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 study area, they are not identical to the actual farms.

Plotting the environmental and economic impacts on a graph shows the trade-offs between environmental improvements (E) and changes in farm profits ($) (Figure 7.1). The horizontal axis in the figure 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 profit 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 7.1, Scenario D is superior to the other three scenarios.

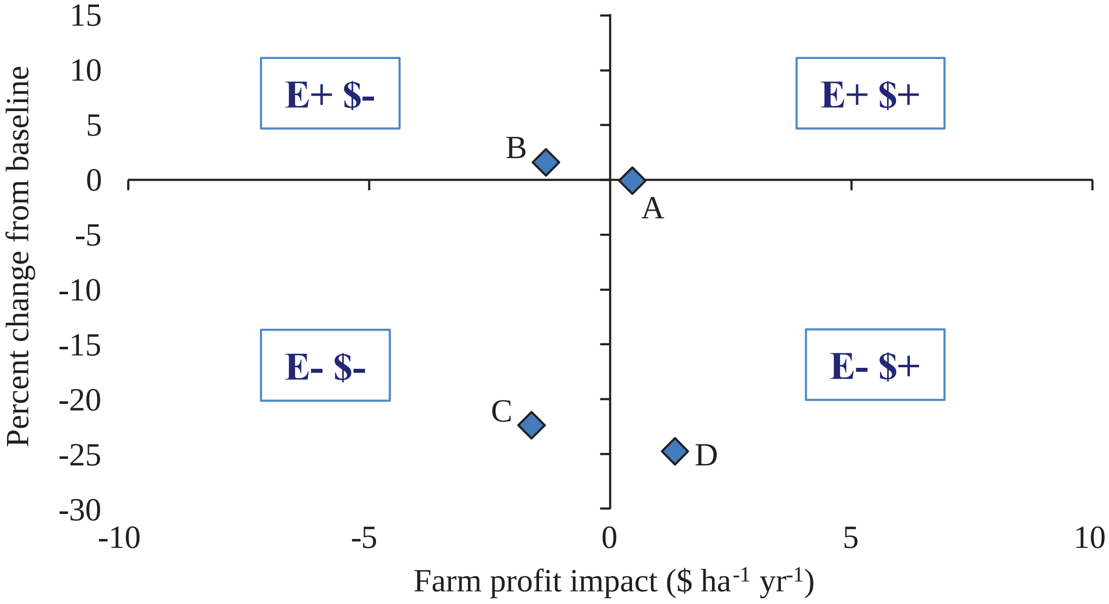

Figure 7.1. Example of the CEEOT model output showing environmental and economic impacts of simulated scenarios, where A, B, C, and D each represent a different scenario of BMPs.

7.4 Results and Discussion of Scenario Simulations

Prior to discussion of the scenario simulation results, it important to recognize that reliability of SWAPP (APEX/SWAT) predictions within each sub-basin was affected by availability of measured data used in model calibration. Generally, it is expected that the results in the AESA sub-basins were more reliable than the results in remaining sub-basins because the model predictions were calibrated for the outlets of each AESA sub-basin.

In the BMP scenario evaluation, the predicted runoff potential was expressed in terms of annual depth (mm) instead of flow ($m^3 s^{-1}$) as discussed in Section 5. Runoff depth is more appropriate for comparison of the effects of BMPs among sub-basins because its value is normalized against the area of each sub-basin and it is directly related to the type and the geographical extent of implemented BMPs. Similarly, the TSS and nutrients loads were normalized against the area of each sub-basin and expressed as export coefficients in Mg ha^{-1} and kg ha^{-1} units, respectively.

7.4.1 Scenario 1: Baseline for the RDR Study Area

APEX simulation results. The baseline scenario of the APEX simulation results showed high variability of predicted values among sub-basins (Table 7.8). In almost all RDR sub-basins, the average annual runoff depths ranged from 0 mm (Sub-basin 10) to almost 31 mm (Sub-basin 24). An exception was Sub-basin 1 where the average runoff depth was nearly 62 mm. This higher runoff can be attributed to the higher precipitation amount when compared to the remaining portion of the study area.

While reviewing the baseline scenario simulation results, there was no attempt to compare the simulated BMP impacts to measured impacts in the field. As mentioned earlier, the land management input data used in the baseline scenario were based on 2001 Census data, which do not fully represent the actual 31-yr farm management practices for the 1975 to 2005 period.

Among AESA sub-basins, there was a strong correlation between predicted runoff depth and predicted TSS nutrient losses. Generally, higher runoff depths resulted in higher TSS and nutrients export coefficients (Table 7.8). The correlation coefficient (R^2) among AESA sub-basins ranged from 0.67 for TN to more than 0.9 for TSS, ON, OP, PO_4-P, and TP (the calculation of R^2 was not included in the report). An exception was for the prediction of NO_3-N, for which the R^2 was near zero due to overestimation of NO_3-N in Sub-basin 13. Also, further calculation showed that there was no correlation between runoff depth and TSS or nutrient export coefficients among the remaining RDR sub-basins. In these sub-basins, the calculated R^2 coefficients were less than or equal to 0.5. If we consider that the APEX predictions were calibrated using the AESA sub-basins and that the predicted flow values were strongly correlated to TSS and nutrient exports, then this also suggests that APEX predictions were more accurate for the AESA sub-basins compared to the other sub-basins.

Table 7.8. APEX estimated annual average values for runoff and export coefficients at the edge-of-field (subarea) within the Red Deer River study area for Scenario 1 (Baseline). The five AESA sub-basins are shown in bold.

		Runoff	Export coefficients^z						
Sub-	Modelled area	depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
basin	(ha)	(mm)	(Mg ha^{-1})	-------------------------- (kg ha^{-1}) --------------------------					
1	**35,394**	**61.8**	**0.057**	**0.46**	**0.09**	**0.32**	**0.72**	**0.78**	**0.81**
2	25,323	17.4	0.036	0.17	0.03	0.06	0.24	0.23	0.27
3	7,049	7.7	0.005	0.14	0.03	0.06	0.46	0.20	0.49
4	3,118	8.6	0.010	0.21	0.04	0.07	0.50	0.28	0.54
5	43,230	18.5	0.031	0.39	0.08	0.10	0.68	0.50	0.75
6	31,060	7.3	0.014	0.04	0.02	0.03	0.07	0.07	0.09
7	1,329	13.0	0.010	0.23	0.07	0.07	0.37	0.30	0.44
8	20,092	8.3	0.017	0.09	0.02	0.02	0.11	0.11	0.13
9	708	12.0	0.004	0.36	0.04	0.06	0.53	0.41	0.57
10	55,995	0.0	0.000	0.00	0.00	0.00	0.00	0.00	0.00
11	39,794	11.9	0.012	0.10	0.03	0.08	0.36	0.18	0.39
12	44,768	12.4	0.020	0.25	0.05	0.07	0.46	0.33	0.51
13	**17,445**	**18.4**	**0.003**	**0.10**	**0.02**	**0.41**	**0.30**	**0.51**	**0.32**
14	20,514	11.8	0.005	0.12	0.02	0.07	0.37	0.19	0.40
15	33,842	3.8	0.007	0.04	0.01	0.02	0.07	0.06	0.09
16	2,763	15.2	0.010	0.18	0.04	0.03	0.20	0.21	0.24
17	4,729	15.1	0.016	0.30	0.05	0.05	0.54	0.35	0.59
18	53,062	11.1	0.018	0.17	0.03	0.06	0.30	0.23	0.33
19	35,641	14.5	0.017	0.15	0.03	0.06	0.39	0.21	0.43
20	29,237	14.9	0.017	0.22	0.04	0.06	0.42	0.28	0.46
21	13,177	11.6	0.017	0.20	0.04	0.09	0.40	0.30	0.45
22	2,673	11.4	0.009	0.24	0.04	0.12	0.47	0.36	0.52
23	13,496	12.0	0.010	0.21	0.04	0.10	0.49	0.30	0.53
24	**4,523**	**30.5**	**0.007**	**0.09**	**0.02**	**0.27**	**0.36**	**0.35**	**0.38**
25	**15,379**	**28.5**	**0.008**	**0.10**	**0.01**	**0.27**	**0.42**	**0.38**	**0.44**
26	66,468	12.6	0.021	0.18	0.04	0.07	0.28	0.26	0.33
27	45,708	7.5	0.016	0.10	0.03	0.04	0.10	0.14	0.13
28	38,123	12.4	0.026	0.12	0.03	0.07	0.25	0.19	0.28
29	17,446	15.8	0.028	0.21	0.04	0.14	0.28	0.34	0.32
30	25,153	13.6	0.022	0.25	0.05	0.11	0.39	0.36	0.44
31	9,073	9.3	0.013	0.10	0.02	0.08	0.25	0.18	0.27
32	**5,796**	**19.8**	**0.004**	**0.03**	**0.01**	**0.19**	**0.16**	**0.22**	**0.17**
33	38,032	20.8	0.024	0.36	0.06	0.14	0.32	0.50	0.38
34	65,215	26.0	0.030	0.18	0.04	0.15	0.63	0.32	0.68
35	87,268	18.3	0.018	0.08	0.02	0.09	0.35	0.17	0.37
36	55,237	18.9	0.026	0.16	0.03	0.11	0.21	0.27	0.24
37	60,650	22.3	0.035	0.21	0.05	0.08	0.10	0.28	0.15
38	19,016	20.4	0.021	0.20	0.03	0.07	0.14	0.27	0.17
39	9,144	21.9	0.023	0.32	0.04	0.11	0.24	0.43	0.28
40	9,817	17.7	0.013	0.45	0.08	0.15	0.33	0.59	0.41
41	81,397	17.4	0.016	0.11	0.02	0.14	0.42	0.25	0.44

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

SWAPP cumulative simulation results. A comparison of the watershed-wide SWAPP simulation results also showed high variability in cumulative average annual runoff depths and in average annual TSS and nutrient export coefficients among sub-basins. The simulated results were greatly affected by the fact that the incoming flow from the upstream portion of the RDR watershed area (1,160,000 ha) into Sub-basin 17 accounted for the majority of flow at the RDR study area outlet (Sub-basin 39). Therefore, the estimated cumulative amount of flow decreased gradually in the main stem of RDR from Sub-basin 17 downstream (Sub-basins 16, 20, 18, 14, 26, 33, 38, and 39) as more of lower runoff potential area was added to the total area. The SWAPP predicted annual runoff depth was eventually reduced from 114 mm at the outlet of Sub-basin 17 to 65 mm at the outlet of Sub-basin 39. Also, the predicted average annual TN export coefficient was reduced from 0.50 to 0.22 kg ha^{-1}. However, the predicted average annual TSS and TP export coefficients were increased from 0.049 to 0.248 Mg ha^{-1} and from 0.06 to 0.20 kg ha^{-1}, respectively (Table 7.9). It is interesting to note that the predicted NO_3-N and PO_4-P fractions accounted for 68 and 100% of TN and TP at the RDR study area outlet (Sub-basin 39), respectively.

At the RDR main tributary outlets (Tr.2, 4, 6, 8, and 9), the cumulative predicted average annual runoff depths ranged from 5.2 mm in Tr.4 (Sub-basin 10) to 23.3 mm in Tr.2 (Sub-basin 12) (Table 7.9). In addition, the cumulative average annual TSS export coefficient ranged from 0.001 in Tr.4 to 0.053 Mg ha^{-1} in Tr.2. Also, the cumulative average annual TN export coefficient ranged from 0.04 kg ha^{-1} in Tr.4 to 0.30 kg ha^{-1} in Tr.2, and the cumulative average annual TP export coefficient ranged from 0.14 kg ha^{-1} in Tr.4 to 0.52 kg ha^{-1} in Tr.2.

7.4.2 Scenario 2: Manure Agronomic Phosphorus Management

The impacts of Scenario 2 reflect improved manure management to reduce excessive application of P. In this scenario, manure nutrients were spread on a greater land area based on crop P uptake rates. Consequently, some subareas that did not receive manure in the baseline scenario received manure nutrients in Scenario 2. Furthermore, due to manure transfers between sub-basins, some sub-basins received more and others received less manure nutrients in Scenario 2 than in the baseline. In general, sub-basins that received more manure nutrients received less inorganic fertilizer nutrients and vice versa (see Table 7.6 for a summary of nutrient application rates). The results of Scenario 2 simulation, expressed as changes from the baseline, are shown in Tables 7.10 (APEX edge-of-field (subarea) results), 7.11 (SWAPP sub-basin outlet results), and 7.12 (economic impacts).

Table 7.9. SWAPP estimated cumulative environmental results at the outlet of each sub-basin for Scenario 1 (Baseline). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Runoff depth	Export coefficients[z]						
	Individual	Cumulative			TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			(mm)	(Mg ha^{-1})	---------------------- (kg ha^{-1}) ----------------------					
17	4,729	1,164,729[y]		114.0	0.049	0.42	0.03	0.09	0.03	0.50	0.06
19	35,641	35,641	Tr.1	14.5	0.019	0.12	0.02	0.06	0.40	0.18	0.42
16	6,541	1,206,912		112.1	0.096	0.34	0.02	0.20	0.05	0.54	0.07
1	35,394	35,394	Tr.2.2.2	61.8	0.057	0.37	0.07	0.32	0.74	0.69	0.81
2	25,323	25,323	Tr.2.2.1	17.4	0.040	0.14	0.02	0.06	0.25	0.20	0.27
5	43,230	103,947	Tr.2.2	33.0	0.060	0.26	0.04	0.17	0.61	0.43	0.65
8	29,263	29,263	Tr.2.1.1	5.7	0.011	0.05	0.01	0.02	0.08	0.07	0.09
9	708	29,971	Tr.2.1	5.8	0.002	0.05	0.01	0.01	0.09	0.06	0.09
12	44,768	178,686	Tr.2	23.3	0.053	0.18	0.03	0.12	0.49	0.30	0.52
20	29,238	1,414,835		98.9	0.165	0.26	0.02	0.18	0.12	0.44	0.14
18	53,062	1,467,897		95.7	0.196	0.21	0.01	0.18	0.13	0.39	0.14
13	17,445	17,445	Tr.3	18.5	0.004	0.08	0.01	0.41	0.30	0.49	0.32
14	20,514	1,505,856		93.7	0.233	0.16	0.01	0.18	0.14	0.35	0.15
3	7,049	7,049	Tr.4.1.1.1.1.1	7.7	0.006	0.12	0.02	0.06	0.47	0.18	0.49
4	3,118	10,167	Tr.4.1.1.1.1	8.0	0.007	0.12	0.02	0.06	0.48	0.18	0.50
11	39,794	49,961	Tr.4.1.1.1	11.2	0.013	0.08	0.02	0.07	0.38	0.15	0.40
6	31,060	81,020	Tr.4.1.1	9.7	0.015	0.06	0.01	0.05	0.27	0.11	0.28
7	1,329	82,349	Tr.4.1	9.8	0.003	0.05	0.01	0.03	0.26	0.09	0.28
10	72,691	155,040	Tr.4	5.2	0.001	0.03	0.01	0.01	0.14	0.04	0.14
15	33,842	33,842	Tr.5	3.8	0.008	0.03	0.01	0.02	0.08	0.05	0.09
26	66,468	1,761,206		81.1	0.260	0.12	0.01	0.16	0.15	0.28	0.15
21	13,177	13,177	Tr.6.1.1	11.7	0.017	0.17	0.03	0.09	0.41	0.26	0.45
22	2,673	15,850	Tr.6.1	11.7	0.004	0.15	0.03	0.07	0.41	0.23	0.44
27	45,708	61,558	Tr.6	8.6	0.018	0.09	0.02	0.05	0.19	0.14	0.21
30	25,153	25,153	Tr.7	13.7	0.028	0.21	0.04	0.11	0.40	0.32	0.44
33	38,032	1,885,950		76.6	0.273	0.10	0.01	0.15	0.16	0.26	0.16
24	4,523	4,523	Tr.8.2.2.1.1.1.1	30.6	0.007	0.07	0.01	0.26	0.36	0.33	0.37
25	15,379	19,902	Tr.8.2.2.1.1	29.0	0.008	0.08	0.01	0.27	0.41	0.35	0.42
29	17,446	37,348	Tr.8.2.2.1	22.9	0.021	0.11	0.02	0.21	0.35	0.32	0.37
31	9,073	46,422	Tr.8.2.2	20.2	0.007	0.10	0.01	0.16	0.33	0.25	0.35
32	5,796	5,796	Tr.8.2.1	19.8	0.004	0.02	0.00	0.19	0.17	0.21	0.17
36	55,237	107,454	Tr.8.2	19.5	0.032	0.10	0.02	0.13	0.27	0.24	0.28
23	13,496	13,496	Tr.8.1.1	12.1	0.010	0.17	0.03	0.10	0.50	0.27	0.53
28	38,123	51,619	Tr.8.1	12.4	0.025	0.11	0.02	0.07	0.32	0.18	0.34
37	60,650	219,724	Tr.8	18.6	0.042	0.11	0.02	0.10	0.24	0.21	0.26
38	19,016	2,124,690		72.4	0.268	0.09	0.01	0.16	0.22	0.26	0.23
34	65,215	65,215	Tr.9.1.2	26.0	0.038	0.14	0.03	0.15	0.64	0.29	0.68
35	87,268	87,268	Tr.9.1.1	18.3	0.020	0.07	0.02	0.09	0.36	0.16	0.37
41	81,397	233,880	Tr.9.1	20.1	0.041	0.09	0.02	0.12	0.46	0.21	0.48
40	9,817	243,698	Tr.9	20.0	0.046	0.08	0.01	0.12	0.46	0.21	0.48
39	**9,144**	**2,377,531**		**64.8**	**0.248**	**0.07**	**0.01**	**0.15**	**0.20**	**0.22**	**0.20**

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

As expected, the edge-of-field TP export coefficients, averaged across each sub-basin, were reduced from baseline levels by 31% among 41 sub-basins (Table 7.10). The export coefficients of OP and PO_4-P were reduced by 5.8 and 34.1% on average among the 41 sub-basins, respectively. The reduction of PO_4-P loss was attributable to the elimination of or reduction in inorganic P fertilizer applications in Scenario 2. Organic P (sediment-bound P) losses were, however, projected to increase in some sub-basins and decline in others, primarily because dynamic manure transfers among sub-basins resulted in some sub-basins receiving more manure P and others receiving less in Scenario 2 as compared to the baseline scenario. Consequently, the percentage changes in P losses at the sub-basin level are in part attributed to the degree to which there was over application of P.

Impacts of Scenario 2 on edge-of-field (subarea) flow and TSS and N losses were mixed. Lower manure application rates may result in reduced vegetation cover and reduced protection of soil surface by manure solids. Consequently, flow and the export coefficient of TSS were increased on average by 1.2 and 15.8% for the 41 sub-basins, respectively (Table 7.10). The increased supplemental N fertilizer applications on most fields, because of reduced manure nutrient rates, may have also resulted in increased NO_3-N losses depending on the timing of nutrient applications and precipitation events. However, on average, NO_3-N loss was reduced by 6.6% and ON loss did not change among the 41 sub-basins.

In general, an increase in TSS losses also led to an increase in organic nutrient losses largely because organic nutrients are transported primarily in sediment-bound form. Similarly, increases in runoff volumes generally lead to increases in soluble (or inorganic) nutrient losses as well as vice versa. Exceptions occurred when a scenario also resulted in changes in the concentration of nutrients, in which case a reduction (or an increase) in soluble nutrient losses may accompany an increase (or a reduction) in runoff volumes. The same exception may hold for the correlation between TSS and organic nutrient losses.

The cumulative changes to flow, TSS, and nutrient values at the outlets of the sub-basins, the tributaries, and the entire study area are presented in Table 7.11. The results for Sub-basins 17, 16, 20, 18, 14, 26, 33, 28, and 39 represent cumulative values in various locations along the RDR reach and at the outlet of the entire study area (Figure 2.4). The model predicted that Scenario 2 had little effect on flow and TSS at the RDR study area outlet compared to the baseline scenario. But as water traveled downstream from Sub-basin 17, the impact of Scenario 2 increased because more upland cultivated area was affected. For example, in Sub-basin 17, the reduction of TN and TP was negligible. But at the downstream Sub-basin 26, the cumulative TN and TP reductions were 1.6 and 27.6%, respectively. Ultimately, at the RDR study area outlet (Sub-basin 39), SWAPP estimated a 3.5% reduction in TN and 28.2% reduction in TP.

The SWAPP results from the head sub-basin outlets (1, 2, 8, 19, 13, 15, 3, 21, 30, 23, 24, 32, 34, and 35) largely mirrored the edge-of-field (subarea) APEX results discussed above. However, in the remaining sub-basins, the SWAPP results varied from APEX results because these sub-basins were impacted by flow received from upstream sub-basins as well as from the upstream portion of the RDR Watershed (Station 05CC002). Furthermore, SWAPP projected a larger reduction in TP export coefficients within sub-basin outlets located along the RDR main tributaries (Tr.2, 4, 6, 8, and 9) when compared to the sub-basin outlets located along the main stem of the RDR (Table 7.11). For example, the estimated TP reduction ranged from 19.7% in Tr.8 (Sub-basin 37) to

Table 7.10. APEX estimated environmental results at the edge -of-field (subarea) within the Red Deer River study area for Scenario 2 (Manure Phosphorus Management). The AESA sub-basins are shown in bold.

	Drainage	Percentage change of flow, TSS, and nutrients from baseline scenario.[z]							
Sub-	area	Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
basin	(ha)	(%)							
1	**35,394**	**0.9**	**0.6**	**23.4**	**-2.3**	**-18.4**	**-40.1**	**6.4**	**-35.8**
2	25,323	0.7	0.6	2.1	5.2	-6.0	-30.5	-0.1	-26.7
3	7,049	-3.6	92.2	-39.8	-9.1	84.3	-46.4	-2.9	-43.9
4	3,118	-2.3	8.0	-44.8	-16.2	77.5	-46.9	-15.7	-44.7
5	43,230	-5.7	0.4	-28.8	-8.3	16.5	-52.7	-19.3	-48.3
6	31,060	4.2	4.1	33.4	14.3	-1.9	-14.8	18.9	-9.2
7	1,329	1.1	-3.9	9.6	-11.3	19.5	-12.5	11.9	-12.3
8	20,092	-2.4	-1.8	-8.5	-1.6	-0.2	-29.4	-6.8	-25.2
9	708	-5.2	304.3	-52.7	-21.9	44.5	-68.0	-39.6	-64.7
10	55,995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	39,794	0.8	7.6	28.4	23.9	15.5	-29.2	22.7	-25.6
12	44,768	0.8	11.3	-21.3	3.1	15.9	-45.1	-13.1	-40.7
13	**17,445**	**11.9**	**-8.4**	**55.4**	**45.0**	**-49.7**	**-7.0**	**-28.3**	**-4.2**
14	20,514	1.0	5.8	-34.4	-29.8	6.6	-45.1	-20.1	-44.2
15	33,842	11.9	15.7	-6.4	-4.5	8.0	-20.7	-1.3	-18.4
16	2,763	-0.4	128.0	15.7	-6.2	19.7	-73.2	16.2	-62.4
17	4,729	-1.9	41.2	-41.1	-29.4	11.7	-64.8	-33.3	-62.0
18	53,062	-0.6	1.9	-22.7	-4.7	0.5	-29.5	-16.9	-27.0
19	35,641	2.4	13.0	35.3	19.9	-2.3	-32.2	24.8	-28.1
20	29,237	-0.5	22.6	-10.4	-3.6	10.4	-46.7	-6.2	-43.1
21	13,177	4.4	15.5	-41.8	-19.3	0.2	-54.6	-28.5	-51.1
22	2,673	2.8	39.7	-69.5	-31.9	-17.8	-53.9	-52.1	-52.0
23	13,496	2.1	19.5	-40.2	-15.6	6.8	-40.0	-25.0	-38.1
24	**4,523**	**-3.8**	**-64.4**	**38.6**	**-7.9**	**-39.6**	**7.2**	**-20.5**	**6.5**
25	**15,379**	**-3.1**	**-1.3**	**-1.3**	**15.2**	**-26.4**	**-46.1**	**-19.5**	**-44.0**
26	66,468	2.3	15.1	-23.3	-12.9	-23.2	-46.9	-23.3	-42.4
27	45,708	4.5	7.3	-45.5	-16.4	-21.2	-42.2	-39.0	-36.0
28	38,123	5.6	3.4	45.4	30.3	-22.3	-31.7	21.6	-25.1
29	17,446	4.4	-5.7	28.9	9.4	-39.6	-16.1	1.8	-12.7
30	25,153	4.4	21.4	-32.9	-20.9	-17.0	-44.4	-28.1	-41.5
31	9,073	2.3	-34.3	25.1	-20.0	-50.5	-17.6	-9.8	-17.7
32	**5,796**	**2.3**	**-13.3**	**94.1**	**-5.9**	**-49.9**	**31.8**	**-32.8**	**30.6**
33	38,032	1.3	5.4	-36.5	-19.5	-18.8	-48.6	-31.6	-43.8
34	65,215	4.6	-5.0	112.6	30.6	-27.3	-29.2	48.6	-25.3
35	87,268	1.9	-11.8	63.4	-4.9	-19.5	-28.0	21.2	-26.7
36	55,237	1.9	-17.1	17.1	-13.8	-43.4	2.7	-7.5	0.6
37	60,650	0.5	10.4	-6.4	-5.6	-40.5	-34.5	-15.5	-25.6
38	19,016	-0.3	1.3	-20.7	-22.6	-20.8	-34.3	-20.8	-32.5
39	9,144	-0.7	2.0	-46.2	-38.3	-45.1	-50.9	-45.9	-49.0
40	9,817	-1.6	23.6	-73.2	-27.0	8.2	-53.9	-52.9	-48.7
41	81,397	1.3	-8.4	120.6	-4.7	-16.1	-31.5	44.3	-30.2

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

Table 7.11. SWAPP estimated cumulative changes at the outlets of each sub-basin for Scenario 2 (Manure Phosphorus Management). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Percentage changes of flow, TSS, and nutrient from baseline scenario[z]							
	Individual	Cumulative		Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	------- (ha) -------			------------------------------------ (%) ------------------------------------							
17	4,729	1,164,729[y]		0.0	0.1	-0.1	-0.1	0.0	-4.7	-0.1	-2.4
19	35,641	35,641	Tr.1	2.4	11.8	35.7	19.9	-2.3	-31.2	23.5	-28.3
16	6,541	1,206,912		0.0	0.1	0.2	0.3	0.0	-10.8	0.2	-7.3
1	35,394	35,394	Tr.2.2.2	0.9	0.6	23.7	-2.1	-18.4	-39.0	4.4	-35.9
2	25,323	25,323	Tr.2.2.1	0.8	0.5	2.2	5.3	-6.0	-29.5	-0.3	-26.8
5	43,230	103,947	Tr.2.2	-0.6	-0.1	-4.9	-4.4	-8.1	-43.6	-6.2	-41.1
8	29,263	29,263	Tr.2.1.1	-2.3	-1.8	-8.5	-1.6	-0.2	-28.2	-6.5	-25.3
9	708	29,971	Tr.2.1	-2.5	13.2	-15.4	-4.7	23.2	-33.4	-9.4	-31.1
12	44,768	178,686	Tr.2	-0.5	0.5	-9.8	-2.1	-3.9	-42.9	-7.5	-40.8
20	29,238	1,414,835		0.0	0.1	-0.6	-0.1	-0.2	-29.4	-0.5	-25.8
18	53,062	1,467,897		0.0	0.1	-1.2	-0.5	-0.2	-28.5	-0.7	-26.0
13	17,445	17,445	Tr.3	11.9	-3.8	56.8	45.6	-49.6	-6.3	-31.3	-4.3
14	20,514	1,505,856		0.0	0.1	-1.2	-0.7	-1.5	-27.9	-1.3	-26.2
3	7,049	7,049	Tr.4.1.1.1.1.1	-3.6	88.3	-39.8	-9.1	84.3	-45.8	2.4	-44.0
4	3,118	10,167	Tr.4.1.1.1.1	-3.2	47.6	-42.1	-12.0	82.2	-45.7	0.3	-44.3
11	39,794	49,961	Tr.4.1.1.1	0.2	5.8	12.5	17.7	31.2	-32.4	20.9	-30.0
6	31,060	81,020	Tr.4.1.1	1.4	4.7	17.5	16.6	24.7	-29.8	21.1	-27.6
7	1,329	82,349	Tr.4.1	1.4	3.8	12.9	11.0	46.5	-28.9	26.1	-27.2
10	72,691	155,040	Tr.4	1.4	2.5	9.4	7.5	95.2	-28.5	32.7	-27.2
15	33,842	33,842	Tr.5	11.9	15.1	-6.7	-4.5	8.0	-20.1	-0.8	-18.5
26	66,468	1,761,206		0.0	0.1	-2.1	-2.4	-1.3	-28.8	-1.6	-27.6
21	13,177	13,177	Tr.6.1.1	4.4	15.1	-42.1	-19.4	0.1	-53.8	-27.0	-51.2
22	2,673	15,850	Tr.6.1	4.1	24.1	-48.1	-23.1	8.6	-53.3	-29.9	-51.5
27	45,708	61,558	Tr.6	4.4	7.1	-46.4	-17.9	-9.2	-47.6	-34.1	-44.4
30	25,153	25,153	Tr.7	4.3	17.3	-33.0	-21.0	-17.0	-43.7	-27.5	-41.6
33	38,032	1,885,950		0.1	0.2	-6.0	-7.3	-1.8	-30.5	-3.5	-29.6
24	4,523	4,523	Tr.8.2.2.1.1.1.1	-3.8	-64.4	40.5	-7.1	-39.6	6.9	-23.0	6.5
25	15,379	19,902	Tr.8.2.2.1.1	-3.2	-14.0	6.1	11.3	-29.3	-35.0	-21.4	-33.8
29	17,446	37,348	Tr.8.2.2.1	-0.8	-6.2	22.4	9.9	-32.5	-27.4	-13.0	-25.5
31	9,073	46,422	Tr.8.2.2	-0.5	-15.4	19.4	2.0	-36.3	-25.6	-14.6	-24.5
32	5,796	5,796	Tr.8.2.1	2.3	-13.3	95.3	-5.9	-49.9	31.5	-35.4	30.6
36	55,237	107,454	Tr.8.2	0.9	-6.8	18.8	-9.6	-40.3	-11.8	-14.6	-11.7
23	13,496	13,496	Tr.8.1.1	2.1	17.6	-40.3	-15.7	6.8	-39.5	-23.1	-38.2
28	38,123	51,619	Tr.8.1	4.6	4.0	17.1	17.6	-10.3	-33.7	7.0	-30.3
37	60,650	219,724	Tr.8	1.3	0.9	7.7	-2.2	-35.8	-21.1	-13.0	-19.7
38	19,016	2,124,690		0.2	0.2	1.7	-5.0	-5.6	-28.9	-2.9	-28.1
34	65,215	65,215	Tr.9.1.2	4.6	-2.3	113.0	30.6	-27.3	-28.3	42.3	-25.4
35	87,268	87,268	Tr.9.1.1	1.9	-10.2	63.5	-5.0	-19.5	-27.7	17.7	-26.7
41	81,397	233,880	Tr.9.1	2.7	-1.5	103.6	9.3	-20.8	-28.7	30.8	-27.4
40	9,817	243,698	Tr.9	2.5	-0.6	71.9	3.2	-19.4	-29.2	17.7	-28.2
39	**9,144**	**2,377,531**		**0.2**	**0.2**	**1.1**	**-5.8**	**-5.8**	**-28.8**	**-3.5**	**-28.2**

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basins 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

44.4% in Tr.6 (Sub-basin 27). But the reduction of TP along the RDR main stem ranged from 2.4 % in Sub-basin 17 to 28.2 % in Sub-basin 39. Also, the predicted changes in TN were higher in the RDR tributaries than in the RDR main stem and ranged from a gain of 32.7% in Tr.4 (Sub-basin 10) to a reduction of 34.1% in Tr.6 (Sub-basin 27). The predicted changes in flow and TSS were also more pronounced in the RDR tributaries than in the RDR main stem. For example, flow ranged from an increase of 4.4% in Tr.6 (Sub-basin 27) to a reduction of 0.5% in Tr.2 (Sub-basin 12). The predicted TSS export coefficients ranged from an increase of 7.1% in Tr.6 (Sub-basin 27) to a reduction of 0.6% in Tr.9 (Sub-basin 40). Such wide variability of predicted TP, TN, flow, and TSS values can be related to two main factors. Firstly, the distribution of manure nutrients varied from one sub-basin to another within each RDR tributary. Secondly, the results at the outlets of sub-basins along the RDR stem were heavily impacted by flow emanating from Station 05CC002.

For the RDR study area, the model predicted that Scenario 2 would save farmers on average about \$0.42 ha^{-1} yr^{-1} (Table 7.12). The results vary considerably depending on farm size. Small farms were projected to have higher net returns while medium- and large-sized farms were shown to incur some increased economic costs. However, these increased costs were lower relative to the reduced costs for the small farms. The cost savings for the small farms was expected because smaller farms usually have more land per animal unit than larger farms. Consequently, smaller farms have more land to utilize manure nutrients, which affords them greater opportunities to benefit from the change in management practices in Scenario 2, which calls for more judicious use of manure nutrients (see for instance Osei et al. 2008a; Osei and Keplinger 2008). Essentially, farms with lower animal density (fewer cows per hectare) have greater opportunity to utilize on-farm generated manure as a nutrient source for crop production, thus reducing commercial fertilizer expenses. On the contrary, farms with greater animal densities have too much manure nutrient produced per hectare and often have to incur high hauling costs to dispose of the manure outside their properties.

In terms of farm types, only swine operations were projected to incur additional costs or reduced profits; whereas, dairy and beef cattle operations are projected to gain financially (Table 7.12). For the AESA sub-basins, farms in four of the five sub-basins were predicted to incur increased economic costs. The economic impacts are largely a function of land area availability. This is because farms that have inadequate land have to incur manure hauling expenses to move manure to suitable land offsite. And in doing so, they lose the opportunity to take advantage of the value of the manure nutrients on their own land.

The economic impacts for all of the RDR sub-basins are presented on Appendix 4. As well, the total economic impact at the study area level (i.e., the summation of all farm-level economic impacts) is provided in Sub-section 7.10, and a discussion of manure hauling characteristics in all the scenarios is presented in Sub-section 7.11.

Table 7.12. Changes in annual net returns for Scenario 2 (Manure Phosphorus Management) relative to the baseline scenario.

		Average size (ha)	Total net return ($ yr^{-1})	Total net return ($ ha^{-1} yr^{-1})
Red Deer River study area		177	73	0.42
Farm size class	Small	122	302	2.48
	Medium	174	-244	-1.41
	Large	454	-325	-0.72
Farm type	Crop	200	0	0.00
	Cattle	113	351	3.12
	Swine	199	-1696	-8.51
	Dairy	185	2802	15.17
AESA sub-basins	1	76	-284	-3.72
	13	296	-1236	-4.17
	24	177	237	1.34
	25	177	-976	-5.50
	32	458	-183	-0.50

7.4.3 Scenario 3: Rotational Grazing and Controlled Access

The results of the rotational grazing scenario predicted improved pasture conditions with a change in cattle grazing management, which increased pasture biomass and quality and reduced feed costs. Output from the environmental models is presented in Tables 7.13 (APEX edge-of-field (subarea) results) and 7.14 (SWAPP sub-basin outlet results). Economic impacts are summarized in Table 7.15.

Edge-of-field impacts of Scenario 3 were small to moderate reductions in virtually all environmental indicators in almost all of the sub-basins (Table 7.13). Relative to the baseline scenario, the reductions ranged from 7 to 15% among flow, TSS, and nutrient parameters averaged for the 41 sub-basins. The edge-of-field reductions were largely the result of improved pasture conditions. Model simulations effectively entailed an improvement from fair to good pasture conditions, implemented as a small improvement in the runoff curve number.

Simulated improvement in pasture conditions were accompanied by reductions in flow, and in TSS and nutrient losses in the majority of the sub-basins (Table 7.13). Improved pasture conditions primarily imply improved vegetative stand, a reduction in the extent of denuded patches, and a more even distribution of directly deposited manure nutrients. The consequences of these primary benefits are reductions in overland runoff volumes, reductions in TSS losses, and reductions in soluble and organic nutrient losses in runoff. With few exceptions, benefits were projected for all sub-basins in the RDR study area. Environmental benefits of rotational grazing in the AESA sub-basins were fairly even, with reductions that ranged from 2.3 to 10.7% for flow, 2.3 to 11.6% for TSS, 0.9 to 9.9% for ON, 1.4 to 13.4% for OP, 0.7 to 28.6% for NO_3-N, 6.0 to 12.9% for PO_4-P, 2.8 to 16.8% for TN, and 5.8 to 13.0% for TP (Table 7.13). In addition, average reductions for the 41 sub-basins ranged from 6.9 to 14.9% among flow and TSS and nutrient export coefficients.

Table 7.13. APEX estimated environmental results at the edge-of-field (subarea) within the Red Deer River study area for Scenario 3 (Rotational Grazing). The AESA sub-basins are shown in bold.

		Percentage changes of flow, TSS, and nutrient from baseline scenario[z]							
Sub-basin	Modelled area (ha)	Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
		(%)							
1	**35,394**	**-8.7**	**-8.0**	**-9.9**	**-13.4**	**-12.0**	**-12.9**	**-10.8**	**-13.0**
2	25,323	-8.6	-8.1	-10.0	-9.8	-19.7	-18.4	-12.5	-17.4
3	7,049	-19.9	-5.6	-37.5	-20.4	-7.6	-26.0	-28.6	-25.6
4	318	-15.5	-8.3	-25.5	-16.8	-2.5	-20.6	-20.0	-20.3
5	4,330	-13.9	-11.4	-22.7	-15.1	-12.1	-22.9	-20.5	-22.1
6	31,060	-22.7	-21.8	-26.0	-22.9	-52.9	-34.5	-37.0	-32.3
7	1,329	-10.2	-3.2	-25.2	-9.1	-11.6	-14.4	-22.0	-13.5
8	20,092	-9.9	-9.1	-13.3	-11.5	-16.2	-17.9	-13.9	-17.0
9	708	-8.3	-1.5	-5.8	-2.9	-1.7	-16.4	-5.2	-15.5
10	55,995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	39,794	-14.1	-5.6	-18.8	-8.4	-24.5	-20.4	-21.4	-19.6
12	44,768	-10.4	-6.9	-17.2	-12.4	-10.5	-19.1	-15.7	-18.5
13	**17,445**	**-7.4**	**-9.5**	**-5.9**	**-5.9**	**-28.6**	**-10.3**	**-24.0**	**-10.1**
14	20,514	-12.1	-10.7	-27.4	-17.1	-6.8	-18.5	-20.2	-18.4
15	33,842	-42.7	-41.2	-49.6	-48.2	-44.5	-44.6	-47.8	-45.1
16	2,763	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	4,729	-8.1	-4.6	-15.7	-9.3	-2.1	-15.8	-13.7	-15.3
18	53,062	-17.5	-13.4	-27.5	-18.6	-13.2	-22.4	-23.9	-22.1
19	35,641	-6.7	-3.1	-2.9	-2.1	-9.8	-12.6	-4.9	-11.7
20	29,237	-8.3	-4.9	-14.7	-9.7	-4.6	-14.3	-12.7	-14.0
21	13,177	-20.9	-14.6	-28.0	-21.9	-19.7	-24.7	-25.4	-24.5
22	2,673	-17.3	-7.9	-23.8	-18.7	-11.6	-17.7	-19.7	-17.8
23	13,496	-15.9	-4.9	-23.1	-17.0	-13.8	-18.1	-20.1	-18.0
24	**4,523**	**-2.3**	**-2.3**	**-2.1**	**-2.0**	**-3.0**	**-6.0**	**-2.8**	**-5.8**
25	**15,379**	**-10.7**	**-11.6**	**-7.5**	**-7.5**	**-20.3**	**-12.7**	**-16.8**	**-12.5**
26	66,468	-10.6	-6.2	-14.1	-11.2	-10.3	-14.4	-13.1	-14.0
27	45,708	-22.7	-19.1	-34.6	-28.6	-26.5	-29.2	-32.4	-29.1
28	38,123	-10.3	-8.0	-7.8	-7.3	-22.6	-19.5	-13.0	-18.2
29	17,446	-4.7	-2.9	-2.7	-2.5	-19.1	-11.5	-9.2	-10.3
30	25,153	-19.7	-9.9	-29.6	-20.7	-20.0	-24.9	-26.7	-24.4
31	9,073	-3.3	-2.1	-1.9	-1.8	-0.8	-6.7	-1.4	-6.4
32	**5,796**	**-3.1**	**-3.5**	**-0.9**	**-1.4**	**-0.7**	**-8.6**	**-0.7**	**-8.4**
33	38,032	-3.2	-2.1	-9.1	-7.6	-0.8	-7.4	-6.8	-7.5
34	65,215	-5.2	-2.5	-1.5	-1.4	-10.8	-11.2	-5.8	-10.5
35	87,268	-4.7	-1.8	-1.4	-1.2	-2.2	-12.0	-1.8	-11.4
36	55,237	-1.9	-1.1	-0.8	-0.8	-1.1	-8.3	-0.9	-7.4
37	60,650	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	19,016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	9,144	-1.0	-0.6	-3.0	-1.0	-0.1	-2.2	-2.3	-2.0
40	9,817	-4.1	-1.9	-10.1	-11.2	-0.7	-5.6	-7.7	-6.6
41	81,397	-3.6	-2.1	-0.6	-0.5	-2.7	-9.6	-1.8	-9.1

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

Table 7.14. SWAPP estimated cumulative changes at the outlets of each sub-basin for Scenario 3 (Rotational Grazing). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Percentage changes of flow, TSS, and nutrient from baseline scenario[z]							
	Individual	Cumulative		Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	------- (ha) -------			--------------------------------- (%) ---------------------------------							
17	4,729	1,164,729[y]		0.0	0.0	0.0	0.0	0.0	-1.1	0.0	-0.6
19	35,641	35,641	Tr.1	-6.6	-3.6	-3.0	-2.2	-9.8	-12.3	-5.2	-11.8
16	6,541	1,206,912		0.0	0.0	-0.1	-0.1	-0.1	-3.6	-0.1	-2.5
1	35,394	35,394	Tr.2.2.2	-8.7	-8.0	-9.9	-13.4	-12.0	-12.9	-10.9	-13.0
2	25,323	25,323	Tr.2.2.1	-8.6	-8.4	-9.9	-9.7	-19.7	-18.1	-12.9	-17.4
5	43,230	103,947	Tr.2.2	-9.9	-10.1	-16.5	-14.1	-12.8	-18.1	-15.1	-17.9
8	29,263	29,263	Tr.2.1.1	-9.9	-9.1	-13.4	-11.5	-16.2	-17.7	-14.1	-17.0
9	708	29,971	Tr.2.1	-9.8	-9.9	-12.6	-11.3	-14.9	-17.5	-13.0	-17.0
12	44,768	178,686	Tr.2	-10.0	-10.3	-16.6	-13.6	-12.5	-18.3	-15.0	-18.0
20	29,238	1,414,835		-0.4	-0.7	-1.5	-2.3	-1.1	-11.9	-1.3	-10.7
18	53,062	1,467,897		-0.4	-0.7	-2.1	-3.6	-1.2	-12.4	-1.7	-11.7
13	17,445	17,445	Tr.3	-7.4	-9.2	-5.9	-6.0	-28.6	-10.3	-24.7	-10.1
14	20,514	1,505,856		-0.5	-0.7	-2.4	-4.1	-2.0	-12.4	-2.2	-11.9
3	7,049	7,049	Tr.4.1.1.1.1.1	-19.9	-6.3	-37.5	-20.4	-7.6	-25.9	-27.3	-25.7
4	3,118	10,167	Tr.4.1.1.1.1	-18.4	-8.6	-32.4	-19.2	-6.1	-24.2	-23.4	-24.0
11	39,794	49,961	Tr.4.1.1.1	-14.7	-8.8	-22.2	-10.7	-21.8	-21.6	-22.0	-21.1
6	31,060	81,020	Tr.4.1.1	-17.0	-14.8	-23.1	-15.3	-27.9	-22.8	-25.4	-22.5
7	1,329	82,349	Tr.4.1	-16.8	-15.3	-23.1	-15.6	-31.6	-22.8	-26.5	-22.5
10	72,691	155,040	Tr.4	-16.9	-18.4	-23.2	-16.7	-40.7	-23.0	-27.9	-22.7
15	33,842	33,842	Tr.5	-42.7	-41.7	-49.5	-48.2	-44.5	-44.7	-47.5	-45.1
26	66,468	1,761,206		-0.7	-0.9	-3.5	-6.8	-2.4	-13.6	-2.9	-13.3
21	13,177	13,177	Tr.6.1.1	-20.9	-14.8	-28.1	-22.2	-19.7	-24.7	-25.1	-24.5
22	2,673	15,850	Tr.6.1	-20.3	-12.9	-27.2	-22.1	-16.8	-23.5	-23.9	-23.4
27	45,708	61,558	Tr.6	-21.9	-20.9	-32.2	-27.4	-22.7	-26.0	-29.1	-26.1
30	25,153	25,153	Tr.7	-19.7	-12.8	-29.8	-20.9	-20.0	-24.8	-26.4	-24.4
33	38,032	1,885,950		-0.8	-1.1	-5.2	-9.6	-2.8	-14.2	-3.7	-14.0
24	4,523	4,523	Tr.8.2.2.1.1.1.1	-2.3	-2.3	-2.2	-2.1	-3.0	-5.9	-2.8	-5.8
25	15,379	19,902	Tr.8.2.2.1.1	-8.7	-9.7	-6.6	-6.5	-16.5	-11.3	-14.2	-11.2
29	17,446	37,348	Tr.8.2.2.1	-7.4	-5.6	-3.9	-3.3	-17.3	-11.2	-12.6	-10.8
31	9,073	46,422	Tr.8.2.2	-7.0	-5.3	-4.1	-3.8	-16.9	-10.5	-11.9	-10.2
32	5,796	5,796	Tr.8.2.1	-3.1	-3.5	-0.9	-1.4	-0.7	-8.6	-0.7	-8.4
36	55,237	107,454	Tr.8.2	-4.2	-3.3	-1.9	-1.7	-9.0	-9.4	-5.9	-9.0
23	13,496	13,496	Tr.8.1.1	-15.8	-6.2	-23.1	-17.0	-13.8	-18.1	-19.7	-18.1
28	38,123	51,619	Tr.8.1	-11.7	-9.2	-13.0	-10.2	-20.1	-19.0	-15.6	-18.5
37	60,650	219,724	Tr.8	-4.0	-3.5	-3.3	-2.6	-8.8	-11.1	-5.9	-10.5
38	19,016	2,124,690		-1.0	-1.2	-4.8	-6.9	-3.3	-12.8	-3.9	-12.6
34	65,215	65,215	Tr.9.1.2	-5.2	-3.4	-1.5	-1.4	-10.8	-11.0	-6.2	-10.6
35	87,268	87,268	Tr.9.1.1	-4.7	-2.1	-1.4	-1.2	-2.2	-11.8	-1.8	-11.4
41	81,397	233,880	Tr.9.1	-4.6	-4.0	-1.2	-1.1	-5.3	-10.7	-3.6	-10.4
40	9,817	243,698	Tr.9	-4.5	-4.2	-2.8	-2.8	-5.1	-10.5	-4.2	-10.2
39	**9,144**	**2,377,531**		**-1.0**	**-1.2**	**-4.8**	**-6.8**	**-3.3**	**-12.7**	**-3.8**	**-12.5**

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Table 7.15. Changes in annual net returns for Scenario 3 (Rotational Grazing) relative to the baseline scenario.

		Average size (ha)	Total net return ($\$ yr^{-1}$)	Total net return ($\$ ha^{-1} yr^{-1}$)
Red Deer River study area		177	679	3.94
Farm size class	Small	122	502	4.13
	Medium	174	1259	7.24
	Large	454	28	0.06
Farm type	Crop	200	656	3.28
	Cattle	113	663	5.89
	Swine	199	187	0.94
	Dairy	185	4201	22.74
AESA sub-basins	1	76	877	11.48
	13	296	389	1.31
	24	177	182	1.03
	25	177	397	2.24
	32	458	94	0.26

The Scenario 3 cumulative effects showed moderate improvements to environmental indicators along the main stem of RDR (Table 7.14). The sub-basin and study area outlet impacts are predicated upon the path of surface water flow between sub-basins as well as inflow into the RDR from the upstream region. Model output predicted reductions in flow (1.0%), TSS (1.2%), ON (4.8%), OP (6.8%), NO_3-N (3.3), PO_4-P (12.7%), TN (3.8%), and TP (12.5%) at the outlet of the RDR study area (Sub-basin 39) (Table 7.14). However, the reduction of flow depths and TSS and nutrient export coefficients were much larger within sub-basin outlets located along the RDR tributaries (Tr.2, 4, 6, 8, and 9) because these sub-basins were not impacted by flow received from the upstream portion of the RDR (Station 05CC002).

Economic impacts of rotational grazing improved pasture biomass production and reduced feed costs. However, there was increased labour hours required for moving livestock between paddocks and paddock fencing costs. Results from FEM simulations showed an overall net financial gain for farms that implement rotational grazing (Table 7.15). Dairy farms in particular were predicted to gain from the improvement in management of pastured livestock. The overall positive economic impact was estimated to be almost \$4 ha^{-1} yr^{-1} for the RDR study area. The economic impacts were similar to the findings of McNitt et al. (1999) who compared intensive rotational grazing systems with open access grazing on dairy farms in the Lake Fork Reservoir watershed of northeast Texas. Their study also indicated that rotational (managed) grazing was economically beneficial compared to open access (unmanaged) grazing.

Results tabulated by farm size groups show that small and medium size farms incurred the most of the benefit from rotational grazing, while larger farms were largely not impacted. This difference in impact among farm size is largely attributed to the distribution of grazing operations in the farm-size groups as well as the fact that larger operations use more intensive feeding options where grazing is not as practical. Furthermore, results tabulated for the AESA sub-basins suggest that farms in Sub-basin 1 would have the greatest economic benefit per hectare, an order of magnitude higher than the average for farms in the other AESA sub-basins.

7.4.4 Scenario 4: Seasonal Bedding and Feeding

The environmental results of the seasonal bedding scenario were very similar to those of the rotational grazing scenario. Edge-of-field (subarea) indicators from APEX simulations (Table 7.16) predicted that moving cattle away from the stream with a well maintained grass field between the new seasonal bedding site and the stream resulted in reductions in flow depths and TSS and nutrient export coefficients (Table 7.16), ranging on average from 6 to 12% among the 41 sub-basins. The magnitudes of the reductions were somewhat smaller than those predicted for the rotational grazing scenario. However, virtually all water quality indicators were improved as in the case of rotational grazing. The size of the downstream grassed field was assumed to be the same as that of the upstream bedding site. The effectiveness of this scenario in reducing flow and TSS and nutrient losses may be greater if the downstream grassed fields were greater in size compared to the upstream bedding sites.

The grassed area downstream of the bedding area acts as a filter strip of sorts, though not likely managed to obtain the effectiveness of vegetative filter strips. Surface flow from the upstream bedding site runs through the grassed area prior to entering the stream. Consequently, there was a reduction in nutrient and TSS losses and runoff volumes that were proportional to the intensity of vegetative cover and the channel length across the grassed area. Improved management of the grassed area can also reduce nutrient losses to the stream. As in the rotational grazing scenario, edge-of-field indicators predicted reductions that ranged from 4.2 to 10.1% for flow, 4.4 to 11.0% for TSS, 1.0 to 6.0% for ON, 6.7 to 14.1% for NO_3-N, 5.7 to 13.9% for PO_4-P, 5.3 to 13.0% for TN, and 4.8 to 15.4% for TP among the five AESA sub-basin (Table 7.16). The export coefficients of OP were reduced in four of the AESA sub-basins (3.5 to 61%) and slightly increased (1.3%) in the fifth AESA sub-basin (Sub-basin 25). In addition, average reductions for the 41 bub-basins ranged from 6.3 to 12.3% among flow depths and TSS and nutrient export coefficients.

The RDR study area outlet and sub-basin outlet impacts predicted by the SWAPP model (Table 7.17) were generally similar or smaller compared to Scenarios 2 and 3, with small improvements for all environmental indicators. The cumulative results at the RDR study area outlet (Sub-basin 39) were reductions in flow and TSS of about 1%, and TN and TP export coefficients reductions of 3.1 and 8.2%, respectively (Table 7.17). Similar to Scenarios 2 and 3, the reductions in Scenario 4 were larger within sub-basin outlets along the RDR tributaries (Tr.2, 4, 6, 8, and 9) because these sub-basins were not impacted by flow received from the upstream portion of the RDR Watershed (Station 05CC002).

Average farm-level economic impact for Scenario 4 (Table 7.18) was a relatively small cost for all farms that implemented the practice. The average cost throughout the entire study area amounted to \$0.44 ha^{-1} yr^{-1}. The small reduction in net returns was caused by increased fencing cost to keep the livestock in the upstream bedding area and the one-time expense of setting up the new bedding site and moving the cattle.

Table 7.16. APEX estimated environmental results at the edge-of-field (subarea) within the Red Deer River study area for Scenario 4 (Seasonal Bedding). The five AESA sub basins are shown in bold.

Sub-basin	Modelled area (ha)	Percentage changes of flow, TSS, and nutrient from baseline scenario[z]							
		Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
		(%)							
1	**35,394**	**-5.2**	**-5.3**	**-6.0**	**-5.4**	**-9.8**	**-7.4**	**-7.5**	**-7.2**
2	25,323	-6.9	-6.1	-6.0	-6.3	-13.9	-11.2	-8.1	-10.7
3	7,049	-6.9	-4.2	-2.7	1.9	-15.9	-9.5	-6.7	-8.8
4	3,118	-5.3	-3.1	-3.2	-3.1	-13.1	-7.1	-5.5	-6.8
5	43,230	-8.5	-7.6	-6.3	-3.9	-18.7	-13.0	-8.9	-12.1
6	31,060	-8.9	-8.6	-10.1	-7.2	-18.1	-16.7	-13.4	-14.8
7	1,329	-7.3	-6.4	-2.5	-3.2	-15.9	-8.9	-5.7	-8.0
8	20,092	-5.7	-5.5	-5.2	-5.0	-13.4	-9.8	-6.9	-9.1
9	708	-8.9	-8.2	-94.9	-91.3	-19.0	-10.4	-84.7	-16.2
10	55,995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	39,794	-4.7	-3.1	-3.8	-2.1	-12.3	-8.4	-7.6	-8.0
12	44,768	-8.8	-8.3	-5.5	-4.3	-18.3	-12.3	-8.3	-11.6
13	**17,445**	**-5.4**	**-7.9**	**-5.2**	**-3.5**	**-6.7**	**-6.4**	**-6.4**	**-6.3**
14	20,514	-7.1	-7.1	-3.0	2.1	-14.5	-9.6	-7.0	-8.9
15	33,842	-16.4	-16.3	-15.2	-10.5	-25.9	-20.0	-19.0	-18.7
16	2,763	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	4,729	-8.8	-9.2	-1.5	0.6	-15.9	-9.2	-3.7	-8.4
18	53,062	-7.4	-6.5	-5.5	-1.1	-16.5	-11.1	-8.3	-10.1
19	35,641	-11.2	-12.9	-3.4	0.9	-19.8	-14.2	-8.0	-13.1
20	29,237	-5.7	-4.4	-2.3	-0.1	-12.3	-6.8	-4.3	-6.3
21	13,177	-7.1	-5.4	-4.9	-4.0	-12.7	-10.2	-7.4	-9.6
22	2,673	-10.6	-11.2	-3.5	-3.2	-15.5	-12.1	-7.5	-11.4
23	13,496	-5.9	-4.4	-3.0	5.8	-10.7	-7.4	-5.4	-6.3
24	**4,523**	**-4.2**	**-6.5**	**-4.8**	**-4.4**	**-7.0**	**-4.9**	**-6.5**	**-4.8**
25	**15,379**	**-4.7**	**-4.4**	**-1.0**	**1.3**	**-7.0**	**-5.7**	**-5.3**	**-5.4**
26	66,468	-7.5	-6.1	-6.4	-3.5	-13.6	-11.6	-8.4	-10.6
27	45,708	-18.0	-16.1	-16.6	-14.6	-27.1	-25.9	-19.4	-23.1
28	38,123	-10.7	-9.7	-9.5	-6.7	-17.5	-15.2	-12.4	-14.3
29	17,446	-3.4	-2.9	-2.1	-1.6	-4.8	-6.1	-3.1	-5.5
30	25,153	-8.8	-5.7	-5.6	1.1	-13.2	-12.3	-8.0	-10.6
31	9,073	-6.1	-5.5	-4.8	-4.4	-9.0	-8.3	-6.7	-8.1
32	**5,796**	**-10.1**	**-11.0**	**-5.2**	**-61.0**	**-14.1**	**-13.9**	**-13.0**	**-15.4**
33	38,032	-5.8	-6.4	-2.2	-1.5	-10.2	-8.6	-4.4	-7.4
34	65,215	-8.5	-8.5	-5.8	-3.5	-16.6	-12.6	-10.7	-12.0
35	87,268	-3.8	-3.1	-3.7	-2.3	-7.7	-6.4	-5.7	-6.2
36	55,237	-3.5	-3.1	-3.6	-3.0	-6.7	-7.4	-4.9	-6.9
37	60,650	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	19,016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	9,144	-2.0	-2.1	-0.7	-1.4	-4.9	-2.8	-1.8	-2.6
40	9,817	-5.8	-6.9	-1.9	-3.2	-13.9	-8.5	-4.9	-7.5
41	81,397	-7.5	-13.8	-6.9	-7.1	-12.2	-9.8	-9.9	-9.7

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

Table 7.17. SWAPP estimated cumulative changes at the outlets of each sub-basin for Scenario 4 (Seasonal Bedding and Feeding). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Percentage changes of flow, TSS, and nutrient from baseline scenario[z]							
	Individual	Cumulative		Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	------- (ha) -------			--------------------------------- (%) ---------------------------------							
17	4,729	1,164,729[y]		0.0	0.0	0.0	0.0	0.0	-0.6	0.0	-0.3
19	35,641	35,641	Tr.1	-11.2	-12.8	-3.4	1.0	-19.8	-13.9	-8.7	-13.1
16	6,541	1,206,912		0.0	-0.1	0.0	0.0	-0.2	-3.6	-0.1	-2.5
1	35,394	35,394	Tr.2.2.2	-5.2	-5.3	-5.9	-5.3	-9.8	-7.3	-7.7	-7.2
2	25,323	25,323	Tr.2.2.1	-6.8	-6.2	-5.9	-6.1	-13.8	-11.0	-8.3	-10.6
5	43,230	103,947	Tr.2.2	-6.2	-6.4	-6.2	-4.6	-12.6	-10.3	-8.6	-10.0
8	29,263	29,263	Tr.2.1.1	-5.7	-5.5	-5.2	-5.0	-13.4	-9.6	-7.1	-9.1
9	708	29,971	Tr.2.1	-5.9	-6.0	-17.9	-13.1	-18.2	-9.9	-17.9	-10.2
12	44,768	178,686	Tr.2	-6.5	-6.8	-6.3	-4.7	-13.5	-10.7	-9.2	-10.4
20	29,238	1,414,835		-0.3	-0.5	-0.5	-0.6	-1.3	-7.4	-0.8	-6.5
18	53,062	1,467,897		-0.3	-0.5	-0.6	-0.7	-1.5	-7.4	-1.0	-6.8
13	17,445	17,445	Tr.3	-5.4	-7.4	-5.2	-3.4	-6.7	-6.4	-6.5	-6.3
14	20,514	1,505,856		-0.3	-0.5	-0.7	-0.6	-1.7	-7.3	-1.2	-6.9
3	7,049	7,049	Tr.4.1.1.1.1.1	-6.9	-4.3	-2.7	2.0	-15.9	-9.4	-7.2	-8.8
4	3,118	10,167	Tr.4.1.1.1.1	-6.4	-4.0	-2.8	0.0	-15.0	-8.5	-6.9	-8.1
11	39,794	49,961	Tr.4.1.1.1	-4.9	-3.6	-3.8	-1.9	-13.1	-8.4	-8.0	-8.1
6	31,060	81,020	Tr.4.1.1	-6.1	-5.8	-5.1	-3.8	-14.1	-9.2	-9.5	-9.0
7	1,329	82,349	Tr.4.1	-6.1	-5.9	-5.4	-4.2	-16.4	-9.3	-9.7	-9.0
10	72,691	155,040	Tr.4	-6.1	-6.5	-5.9	-4.8	-20.4	-9.3	-9.8	-9.1
15	33,842	33,842	Tr.5	-16.5	-16.2	-15.2	-10.4	-25.9	-19.7	-19.5	-18.7
26	66,468	1,761,206		-0.4	-0.6	-1.1	-1.5	-2.0	-7.8	-1.6	-7.5
21	13,177	13,177	Tr.6.1.1	-7.1	-5.5	-5.0	-4.1	-12.7	-10.1	-7.7	-9.6
22	2,673	15,850	Tr.6.1	-7.6	-8.2	-4.9	-4.3	-14.9	-10.4	-8.1	-10.0
27	45,708	61,558	Tr.6	-14.4	-15.9	-12.6	-12.3	-22.3	-16.7	-15.8	-16.2
30	25,153	25,153	Tr.7	-8.7	-6.2	-5.7	1.1	-13.3	-11.9	-8.3	-10.7
33	38,032	1,885,950		-0.5	-0.7	-1.6	-2.2	-2.5	-8.3	-2.1	-8.0
24	4,523	4,523	Tr.8.2.2.1.1.1.1	-4.2	-6.5	-4.8	-4.3	-7.0	-4.9	-6.6	-4.8
25	15,379	19,902	Tr.8.2.2.1.1	-4.6	-4.8	-1.5	0.4	-7.0	-5.4	-5.7	-5.3
29	17,446	37,348	Tr.8.2.2.1	-4.2	-3.7	-1.9	-1.2	-6.3	-5.6	-4.7	-5.4
31	9,073	46,422	Tr.8.2.2	-4.4	-4.8	-2.6	-2.1	-6.8	-6.0	-5.2	-5.9
32	5,796	5,796	Tr.8.2.1	-10.1	-11.0	-4.9	-61.2	-14.1	-14.2	-13.2	-15.3
36	55,237	107,454	Tr.8.2	-4.2	-4.1	-3.3	-3.3	-7.3	-6.8	-5.6	-6.6
23	13,496	13,496	Tr.8.1.1	-5.9	-4.5	-2.9	5.9	-10.7	-7.1	-5.8	-6.4
28	38,123	51,619	Tr.8.1	-9.5	-9.8	-7.5	-3.6	-16.5	-11.9	-10.8	-11.3
37	60,650	219,724	Tr.8	-3.7	-3.8	-2.7	-1.7	-7.2	-7.5	-4.9	-7.0
38	19,016	2,124,690		-0.8	-0.9	-2.0	-2.4	-3.7	-8.4	-3.0	-8.2
34	65,215	65,215	Tr.9.1.2	-8.5	-8.5	-5.7	-3.5	-16.6	-12.5	-11.2	-12.0
35	87,268	87,268	Tr.9.1.1	-3.8	-3.2	-3.7	-2.4	-7.7	-6.3	-5.9	-6.2
41	81,397	233,880	Tr.9.1	-6.6	-7.6	-5.6	-4.4	-12.5	-9.8	-9.7	-9.6
40	9,817	243,698	Tr.9	-6.6	-7.6	-4.9	-4.2	-12.6	-9.7	-9.5	-9.6
39	**9,144**	**2,377,531**		**-0.8**	**-1.0**	**-1.9**	**-2.4**	**-3.7**	**-8.3**	**-3.1**	**-8.2**

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Table 7.18. Change in annual net returns for Scenario 4 (Seasonal Bedding and Feeding) relative to the baseline scenario.

		Average size (ha)	Total net return ($ yr^{-1})	Total net return ($ $ha^{-1}yr^{-1}$)
Red Deer River study area		177	-75	-0.44
Farm size class	Small	122	-62	-0.51
	Medium	174	-128	-0.73
	Large	454	-1	0
Farm type	Crop	200	-75	-0.37
	Cattle	113	-80	-0.71
	Swine	199	-22	-0.11
	Dairy	185	-169	-0.91
AESA sub-basins	1	76	-84	-0.10
	13	296	-33	-0.11
	24	177	-10	-0.06
	25	177	-37	-0.21
	32	458	-10	-0.03

7.4.5 Scenario 5: Grassed Waterways

As specified in the scenario descriptions, grassed waterways were simulated only for fields where soil losses were relatively significant. Only a small percentage of subareas were simulated with grassed waterways because baseline soil loss estimates from APEX were very small for most subareas. The APEX results indicated that grassed waterway simulation concentrated on a few subareas, and hence, a few sub-basins (Table 7.19). However, there were reductions in edge-of-field (subarea) indicators wherever the grassed waterways were simulated. A standard 15-m width was assumed for the grassed waterways in this study. The impact would increase with wider grassed waterways, and the reverse would be true for narrower grassed waterways.

A grassed waterway acts as an unmanaged grassed filter strip lining the bottoms of drainage channels in cropped fields. The filtering mechanism of grassed waterways reduces flow and traps TSS and nutrients in addition to nutrient assimilation by the waterway vegetation. Consequently, there were reductions in flow and in TSS and nutrient export coefficients (Table 7.19). The average reductions varied among the sub-basins primarily due to the distribution of grassed waterways. Sub-basins with greater reductions had greater proportions of their area under grass cover. In the five AESA sub-basins, the reduction ranged from 0 to 19.1% for flow, 0 to 24.3% for TSS, 0 to 13.5% for ON, 0 to 10.5% for OP, 0 to 28.0% for NO_3-N, 0 to 21.6% for PO_4-P, 0 to 24.5% for TN, and 0 to 20.1% for TP. The large number of zero values in Table 7.19 indicates that the environmental indicators did not change. This is because a majority of sub-basins (26 out of 41) did not require implementation of grassed waterways due to very low erosion potential. In addition, average reductions for the 41 sub-basins ranged from 1.3 to 5.9% among flow depths and TSS and nutrient export coefficients.

Table 7.19. APEX estimated environmental results at the edge-of-field (subarea) within the Red Deer River study area for Scenario 5 (Grassed Waterways). The five AESA sub-basins are shown in bold.

Sub-basin	Modelled area (ha)	Percentage changes of flow, TSS, and nutrient from baseline scenario[z]							
		Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
		(%)							
1	**35,394**	**0.0**[y]	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
2	25,323	-3.4	-3.4	-4.0	-2.8	-3.8	-4.6	-3.9	-4.4
3	7,049	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	3,118	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	43,230	-4.6	-9.5	-4.1	2.5	-6.1	-4.1	-4.5	-3.5
6	31,060	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1,329	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	20,092	-7.4	-9.1	-11.0	-2.5	-9.3	-8.9	-10.6	-7.9
9	708	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	55,995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	39,794	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	44,768	-3.1	-17.1	-1.2	7.5	-3.4	-2.9	-1.7	-1.9
13	**17,445**	**-19.1**	**-23.0**	**4.0**	**4.5**	**-16.6**	**-21.6**	**-12.4**	**-20.1**
14	20,514	-0.4	-1.0	1.6	5.9	-0.3	-0.3	0.9	0.1
15	33,842	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	2,763	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	4,729	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	53,062	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	35,641	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	29,237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	13,177	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	2,673	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	13,496	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	**4,523**	**-12.4**	**-24.3**	**-13.5**	**-10.5**	**-28.0**	**-13.9**	**-24.5**	**-13.8**
25	**15,379**	**-8.7**	**-10.2**	**5.2**	**10.5**	**-7.2**	**-8.0**	**-3.8**	**-7.4**
26	66,468	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	45,708	-1.1	-3.0	0.3	1.2	1.7	-1.4	0.7	-0.8
28	38,123	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	17,446	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	25,153	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	9,073	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	**5,796**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
33	38,032	-5.1	-34.8	-9.5	-7.7	-21.6	-11.7	-12.9	-11.0
34	65,215	-6.0	-25.1	-19.9	-16.7	-20.9	-13.7	-20.4	-13.9
35	87,268	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	55,237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	60,650	-10.3	-23.0	-23.5	-7.2	-11.2	-13.3	-20.3	-11.4
38	19,016	-1.6	-15.6	-15.1	-9.3	-2.4	-1.5	-11.9	-2.7
39	9,144	-2.0	-20.1	-9.6	-10.8	-10.2	-5.8	-9.8	-6.5
40	9,817	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	81,397	-3.8	-24.1	-11.1	-16.9	-15.6	-8.5	-13.6	-9.0

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Zero value indicates that the BMP was not required in a particular sub-basin and the environmental indicators did not change.

The RDR study area and sub-basin outlet cumulative impacts from SWAPP simulation were generally small reductions (Table 7.20). The cumulative results were small because the impacts from the few sub-basins with noticeable edge-of-field effects (sub-basin) from the grassed waterways were dissipated when combined with incoming flow from upstream of the RDR study area as well as flow from other sub-basins where there were negligible edge-of-field impacts. Impacts on flow and TSS and nutrient export coefficients at the RDR study area outlet (Sub-basin 39) were about a 0.5% reduction in flow and TSS, and 2.4 and 3.3% reductions in TN and TP export coefficients, respectively, relative to the baseline (Table 7.20).

The model predicted a reduction in net returns, with an average reduction of nearly $\$3\ h^{-1}\ yr^{-1}$ for the entire RDR study area (Table 7.21). The economic impact was similar for farm types, farm sizes, and AESA sub-basins. The reduction in net returns primarily reflect the opportunity cost of the small strip of land that is grassed and taken out of crop or forage production.

Table 7.20. SWAPP estimated cumulative changes at the outlets of each sub-basin for Scenario 5 (Grassed Waterway). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Percentage changes of flow, TSS, and nutrient from baseline scenario[z]							
	Individual	Cumulative		Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	------- (ha) -------			---------------------------------- (%) ------------------------------------							
17	4,729	1,164,729[y]		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	35,641	35,641	Tr.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	6,541	1,206,912		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	35,394	35,394	Tr.2.2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	25,323	25,323	Tr.2.2.1	-3.4	-3.2	-3.9	-2.8	-3.7	-4.5	-3.9	-4.4
5	43,230	103,947	Tr.2.2	-1.5	-2.9	-2.5	1.1	-2.0	-2.4	-2.3	-2.1
8	29,263	29,263	Tr.2.1.1	-7.4	-9.1	-10.9	-2.5	-9.2	-8.6	-10.5	-7.9
9	708	29,971	Tr.2.1	-7.0	-8.0	-9.3	-2.7	-8.9	-7.4	-9.3	-7.0
12	44,768	178,686	Tr.2	-1.9	-3.8	-2.4	2.9	-2.3	-2.5	-2.3	-2.3
20	29,238	1,414,835		-0.1	-0.2	-0.2	0.4	-0.2	-1.3	-0.2	-1.1
18	53,062	1,467,897		-0.1	-0.2	-0.2	0.4	-0.2	-1.1	-0.2	-1.0
13	17,445	17,445	Tr.3	-19.0	-21.7	4.6	5.3	-16.5	-21.1	-12.8	-20.0
14	20,514	1,505,856		-0.1	-0.2	-0.1	0.6	-0.6	-1.6	-0.4	-1.4
3	7,049	7,049	Tr.4.1.1.1.1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	3,118	10,167	Tr.4.1.1.1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	39,794	49,961	Tr.4.1.1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	31,060	81,020	Tr.4.1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1,329	82,349	Tr.4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	72,691	155,040	Tr.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	33,842	33,842	Tr.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	66,468	1,761,206		-0.1	-0.2	-0.1	0.5	-0.6	-1.3	-0.4	-1.2
21	13,177	13,177	Tr.6.1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	2,673	15,850	Tr.6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	45,708	61,558	Tr.6	-0.7	-2.1	0.2	0.9	1.0	-0.5	0.4	-0.4
30	25,153	25,153	Tr.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	38,032	1,885,950		-0.1	-0.2	-0.7	-0.7	-0.9	-1.6	-0.8	-1.6
24	4,523	4,523	Tr.8.2.2.1.1.1.1	-12.3	-24.3	-13.1	-9.7	-28.0	-13.9	-24.9	-13.8
25	15,379	19,902	Tr.8.2.2.1.1	-9.5	-13.1	2.4	7.4	-11.8	-9.1	-8.6	-8.7
29	17,446	37,348	Tr.8.2.2.1	-6.4	-3.7	0.8	1.7	-8.1	-5.5	-5.0	-5.2
31	9,073	46,422	Tr.8.2.2	-5.8	-2.7	0.1	0.6	-7.6	-4.6	-4.6	-4.4
32	5,796	5,796	Tr.8.2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	55,237	107,454	Tr.8.2	-2.6	-1.2	0.1	0.2	-3.8	-2.5	-2.1	-2.3
23	13,496	13,496	Tr.8.1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	38,123	51,619	Tr.8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	60,650	219,724	Tr.8	-4.7	-7.0	-10.1	-3.5	-4.7	-3.0	-7.5	-3.0
38	19,016	2,124,690		-0.4	-0.5	-2.6	-3.1	-2.2	-3.3	-2.4	-3.3
34	65,215	65,215	Tr.9.1.2	-6.0	-19.7	-19.8	-16.5	-20.9	-13.6	-20.3	-13.7
35	87,268	87,268	Tr.9.1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	81,397	233,880	Tr.9.1	-3.3	-8.2	-11.6	-12.2	-13.3	-8.2	-12.6	-8.3
40	9,817	243,698	Tr.9	-3.2	-7.3	-9.5	-10.2	-12.7	-7.9	-11.4	-8.0
39	**9,144**	**2,377,531**		**-0.4**	**-0.5**	**-2.8**	**-3.4**	**-2.2**	**-3.3**	**-2.4**	**-3.3**

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Table 7.21. Change in annual net returns for Scenario 5 (Grassed Waterways) relative to the baseline scenario.

		Average size (ha)	Total net return ($ yr^{-1})	Total net return ($ $ha^{-1}yr^{-1}$)
Red Deer River study area		177	-485	-2.82
Farm size class	Small	122	-396	-3.26
	Medium	174	-420	-2.42
	Large	454	-1174	-2.59
Farm type	Crop	200	-554	-2.77
	Cattle	113	-316	-2.81
	Swine	199	-732	-3.67
	Dairy	185	-459	-2.49
AESA sub-basins	1	76	-229	-3.00
	13	296	-749	-2.53
	24	177	-638	-3.61
	25	177	-611	-3.44
	32	458	-917	-2.51

7.4.6 Scenario 6: Riparian Setbacks

Riparian setbacks were only simulated for riparian subareas (fields adjoining streams) and were very effective per unit of treated area. However, their impacts averaged in a given sub-basin were moderate in magnitude. The predicted results showed a very large range in effectiveness from one sub-basin to another (Table 7.22), largely due to the fact that there were significant variations in the proportion of each sub-basin that was simulated with riparian setbacks. The model predicted for the five AESA sub-basins edge-of-field (subarea) reductions that ranged from 0 to 12.3% for flow, 0 to 16.2% for TSS, 0 to 21.0% for ON, 0 to 20.8% for OP, 0 to 17.8% for NO_3-N, 0 to 18.7% for PO_4-P, 0 to 17.9% for TN, and 0 to 18.4% for TP. The predicted maximum reduction for NO_3-N and PO_4-P was 81.3 and 74.2%, respectively, in Sub-basin 15. In addition, average reductions for the 41 sub-basins ranged from 11.4 to 27.8% among flow depths and TSS and nutrient export coefficients.

Riparian setbacks were predicted to be more effective per unit area than most of the other structural BMPs. Setbacks were simulated with no grazing and no crop production. In addition, the setbacks were simulated with permanent grass cover as well as a forested strip, which can reduce runoff losses. Consequently, sub-basins with a denser stream network were impacted more by riparian setbacks.

Because the land uses in each sub-basin were largely dominated by subareas simulated in APEX, the SWAPP results for upstream sub-basins are largely identical. The cumulative reductions of flow depths and TSS and nutrient export coefficients in Sub-basin 39 ranged from 1.2 to 17.1% (Table 7.23). Though similar in magnitude to the reductions predicted for Scenario 3, the reductions for Scenario 6 were slightly greater than for Scenario 3.

Table 7.22. APEX estimated environmental results at the edge-of-field (subarea) within the Red Deer River study area for Scenario 6 (Riparian Setbacks). The five AESA sub-basin are shown in bold.

		Percentage changes of flow, TSS, and nutrient from baseline scenario[z]							
Sub-basin	Modelled area (ha)	Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
		(%)							
1	**35,394**	**-2.5**	**-2.9**	**6.1**	**5.8**	**-13.1**	**-6.5**	**-1.7**	**-5.1**
2	25,323	-4.6	-7.3	-14.8	-5.2	-17.3	-12.7	-15.5	-11.9
3	7,049	-18.7	-15.3	-9.1	-16.7	-57.4	-32.4	-23.5	-31.4
4	3,118	0.0[y]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	43,230	-6.0	-6.8	-4.8	-3.2	-24.6	-12.6	-9.0	-11.7
6	31,060	-23.5	-25.7	-39.5	-29.3	-47.0	-46.8	-42.6	-43.5
7	1,329	-7.1	-32.0	-6.8	-14.8	-36.4	-17.8	-13.8	-17.3
8	20,092	-12.2	-14.9	-17.8	-10.4	-40.5	-29.2	-22.4	-26.4
9	708	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	55,995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	39,794	-11.1	-15.2	-12.4	-19.4	-38.1	-28.4	-23.9	-27.8
12	44,768	-8.2	-12.4	-3.2	-0.1	-35.1	-19.9	-10.3	-18.1
13	**17,445**	**-12.3**	**-13.1**	**-15.7**	**-13.0**	**-17.8**	**-18.7**	**-17.4**	**-18.4**
14	20,514	-15.8	-21.4	-5.1	-2.3	-44.2	-29.8	-18.8	-28.2
15	33,842	-61.5	-61.3	-64.6	-62.8	-81.3	-74.2	-70.5	-72.6
16	2,763	-3.3	-20.9	-8.9	-5.9	-5.7	-3.2	-8.5	-3.7
17	4,729	-12.7	-27.4	-7.1	-9.6	-48.2	-20.6	-13.2	-19.8
18	53,062	-26.2	-34.1	-30.6	-25.3	-61.5	-46.8	-38.3	-44.7
19	35,641	-18.0	-30.9	-16.6	-18.2	-47.2	-30.0	-25.2	-29.1
20	29,237	-16.3	-28.5	-12.1	-13.0	-51.7	-28.0	-19.9	-26.7
21	13,177	-12.5	-25.4	-19.3	-8.0	-28.6	-23.9	-22.2	-22.3
22	2,673	-15.2	-39.6	-8.9	-3.9	-33.4	-26.9	-17.1	-25.0
23	13,496	-15.4	-15.7	-14.8	-15.7	-33.9	-24.4	-21.0	-23.7
24	**4,523**	**-5.6**	**-16.2**	**-21.4**	**-20.8**	**-16.7**	**-8.3**	**-17.9**	**-8.8**
25	**15,379**	**-7.7**	**-9.5**	**11.7**	**10.1**	**-15.4**	**-11.8**	**-7.9**	**-11.1**
26	66,468	-17.8	-24.3	-30.4	-18.5	-38.2	-33.9	-32.6	-31.9
27	45,708	-24.0	-26.2	-31.7	-25.6	-43.5	-42.3	-34.9	-38.3
28	38,123	-15.2	-20.2	-26.6	-14.8	-30.5	-29.0	-28.0	-27.5
29	17,446	-9.0	-19.9	-17.2	-11.9	-15.7	-22.3	-16.6	-20.9
30	25,153	-26.8	-31.1	-39.6	-29.3	-41.5	-42.3	-40.2	-40.7
31	9,073	-4.4	-16.0	-19.5	-18.3	-12.8	-11.0	-16.4	-11.4
32	**5,796**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
33	38,032	-6.7	-40.0	-16.8	-14.3	-28.4	-14.0	-20.0	-14.0
34	65,215	-7.5	-29.5	-24.6	-21.3	-23.6	-16.0	-24.1	-16.3
35	87,268	-6.4	-28.1	-29.6	-21.1	-24.2	-16.1	-26.9	-16.4
36	55,237	-2.6	-10.5	-28.5	-10.8	-7.3	-8.7	-19.8	-9.0
37	60,650	-2.7	-10.8	-14.1	0.4	-2.9	-3.4	-11.1	-2.3
38	19,016	-4.5	-30.5	-20.7	-13.2	-7.4	-4.5	-17.4	-5.9
39	9,144	-2.5	-26.4	-13.1	-15.1	-13.4	-7.2	-13.2	-8.3
40	9,817	-3.7	-33.8	-4.0	-11.5	-29.2	-12.6	-10.3	-12.4
41	81,397	-7.5	-35.5	-14.7	-23.2	-24.6	-14.0	-20.2	-14.5

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Zero value indicates that the BMP was not required in a particular sub-basin and the environmental indicators did not change.

Table 7.23. SWAPP estimated cumulative changes at the outlets of each sub-basin for Scenario 6 (Riparian Setbacks). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Percentage changes of flow, TSS, and nutrient from baseline scenario[z]							
	Individual	Cumulative		Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	------- (ha) ------			-------------------------------- (%) ----------------------------------							
17	4,729	1,164,729[y]		0.0	0.0	0.0	0.0	-0.1	-1.4	0.0	-0.7
19	35,641	35,641	Tr.1	-18.0	-28.7	-16.7	-18.5	-47.2	-29.8	-26.5	-29.1
16	6,541	1,206,912		-0.1	-0.2	-0.2	-0.5	-0.4	-7.9	-0.3	-5.5
1	35,394	35,394	Tr.2.2.2	-2.5	-2.9	6.2	5.8	-13.1	-6.2	-2.7	-5.2
2	25,323	25,323	Tr.2.2.1	-4.6	-6.6	-14.8	-5.3	-17.3	-12.4	-15.6	-11.9
5	43,230	103,947	Tr.2.2	-3.6	-4.2	-1.5	0.1	-16.5	-9.6	-7.3	-9.0
8	29,263	29,263	Tr.2.1.1	-12.2	-14.9	-17.7	-10.3	-40.5	-28.4	-23.2	-26.5
9	708	29,971	Tr.2.1	-11.6	-13.1	-15.6	-10.4	-47.2	-24.1	-20.5	-23.0
12	44,768	178,686	Tr.2	-4.5	-4.8	-2.4	-0.2	-19.8	-12.3	-9.2	-11.7
20	29,238	1,414,835		-0.3	-0.5	-0.5	-0.9	-2.3	-11.3	-1.3	-10.0
18	53,062	1,467,897		-0.4	-0.6	-1.3	-2.7	-2.9	-13.9	-2.1	-12.9
13	17,445	17,445	Tr.3	-12.3	-12.2	-15.7	-12.9	-17.6	-18.4	-17.3	-18.2
14	20,514	1,505,856		-0.4	-0.6	-1.4	-2.9	-3.5	-14.3	-2.5	-13.6
3	7,049	7,049	Tr.4.1.1.1.1.1	-18.6	-15.4	-8.9	-16.3	-57.4	-32.2	-25.4	-31.4
4	3,118	10,167	Tr.4.1.1.1.1	-12.5	-9.1	-4.9	-9.4	-39.0	-21.8	-16.6	-21.3
11	39,794	49,961	Tr.4.1.1.1	-11.3	-13.5	-11.2	-18.0	-39.6	-27.0	-24.0	-26.6
6	31,060	81,020	Tr.4.1.1	-14.8	-17.9	-17.3	-21.9	-41.0	-29.0	-28.9	-28.7
7	1,329	82,349	Tr.4.1	-14.6	-17.8	-17.9	-21.8	-45.7	-28.9	-28.8	-28.6
10	72,691	155,040	Tr.4	-14.6	-14.9	-19.1	-22.3	-50.3	-29.1	-27.6	-28.8
15	33,842	33,842	Tr.5	-61.8	-60.6	-64.7	-63.0	-81.2	-73.7	-71.4	-72.6
26	66,468	1,761,206		-0.7	-0.9	-3.3	-7.7	-4.6	-17.4	-4.0	-17.0
21	13,177	13,177	Tr.6.1.1	-12.5	-24.9	-19.4	-8.2	-28.7	-23.5	-22.7	-22.4
22	2,673	15,850	Tr.6.1	-12.9	-29.2	-17.2	-8.2	-33.0	-23.9	-22.3	-22.9
27	45,708	61,558	Tr.6	-20.0	-24.3	-26.8	-21.9	-39.4	-31.2	-30.9	-30.2
30	25,153	25,153	Tr.7	-26.8	-28.3	-39.4	-29.2	-41.4	-41.8	-40.1	-40.6
33	38,032	1,885,950		-0.8	-1.2	-5.6	-11.3	-5.7	-18.5	-5.7	-18.2
24	4,523	4,523	Tr.8.2.2.1.1.1.1	-5.6	-16.1	-21.3	-20.7	-16.7	-8.4	-17.7	-8.7
25	15,379	19,902	Tr.8.2.2.1.1	-7.2	-10.9	6.5	4.9	-15.7	-11.0	-10.7	-10.6
29	17,446	37,348	Tr.8.2.2.1	-7.8	-15.3	-10.0	-8.4	-15.7	-15.0	-13.7	-14.7
31	9,073	46,422	Tr.8.2.2	-7.5	-13.1	-11.8	-10.5	-15.8	-14.4	-14.2	-14.3
32	5,796	5,796	Tr.8.2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	55,237	107,454	Tr.8.2	-4.6	-6.8	-22.8	-10.7	-11.0	-11.5	-16.1	-11.5
23	13,496	13,496	Tr.8.1.1	-15.4	-15.2	-14.8	-15.6	-33.9	-24.2	-21.8	-23.7
28	38,123	51,619	Tr.8.1	-15.2	-18.1	-22.9	-15.2	-32.8	-27.0	-26.5	-26.2
37	60,650	219,724	Tr.8	-5.7	-8.6	-19.2	-6.2	-12.7	-15.3	-16.1	-14.6
38	19,016	2,124,690		-1.2	-1.6	-8.5	-12.0	-7.8	-17.3	-8.0	-17.1
34	65,215	65,215	Tr.9.1.2	-7.4	-23.3	-24.5	-21.2	-23.5	-15.9	-24.0	-16.2
35	87,268	87,268	Tr.9.1.1	-6.4	-25.5	-29.6	-21.1	-24.2	-16.2	-26.6	-16.4
41	81,397	233,880	Tr.9.1	-7.1	-16.3	-22.3	-21.8	-24.2	-15.6	-23.4	-15.8
40	9,817	243,698	Tr.9	-7.0	-15.1	-19.0	-20.2	-24.5	-15.5	-22.3	-15.7
39	**9,144**	**2,377,531**		**-1.2**	**-1.6**	**-8.6**	**-12.3**	**-7.8**	**-17.2**	**-8.1**	**-17.1**

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Scenario 6 resulted in a predicted reduction in net returns (Table 7.24), similar to grassed waterways. Riparian setbacks and grassed waterways are similar in that land is taken out of crop production and used for the BMP. The cost impacts are slightly larger for riparian setbacks compared to grass waterways due to a higher establishment cost of the riparian areas. Riparian setback areas cost approximately \$1361 ha^{-1} of buffer (adjusted from Michie 2010) and an annual maintenance cost of \$18 ha^{-1} (assuming the same cost as an unmanaged wetland). However, the cost per farm was much smaller since the setback areas were a small portion of the farms. A similar establishment cost was used in the wetland scenario. Overall, the predicted average cost for Scenario 6 was \$4.72 ha^{-1} yr^{-1} for the RDR study area, and the impacts were similar for farm types and farm sizes and sub-basins (Table 7.24).

7.4.7 Scenario 7: Wetland Restoration

On average at the edge-of-field level, the model predicted that wetland restoration resulted in a small to moderate reduction in flow and nutrient export coefficients (Table 7.25). In a few cases, such as in Sub-basin 1, nutrient losses may actually increase due to an increase in organic nutrient losses from the wetland area. However, flow depths and TSS and soluble nutrient export coefficients were largely reduced. The average reduction in flow depths and TSS and most nutrient export coefficients ranged from 2.7 to 5.2% among the 41 sub-basins (Table 7.25). The exception was for OP, which increased on average by 3.7% for the 41 sub-basins. In general, wetland impacts depend largely on the scale of change in wetland area that was simulated relative to the baseline, as well as the water, TSS, and nutrient retention characteristics assumed for the wetlands. However, in this project, the size and effectiveness of restored wetlands, the magnitude of flow, TSS, and nutrient reductions obtained from upstream BMPs in each sub-basin were drastically reduced at the outlet of the sub-basin because the large wetland was already retaining most of the flow, sediment, and nutrients regardless of the size of upstream wetland restoration.

Table 7.24. Change in annual net returns for Scenario 6 (Riparian Setbacks) relative to the baseline scenario.

		Average size (ha)	Total net return (\$ yr^{-1})	Total net return (\$ ha^{-1} yr^{-1})
Red Deer River study area		177	-812	-4.72
Farm size class	Small	122	-671	-5.52
	Medium	174	-746	-4.29
	Large	454	-1799	-3.96
Farm type	Crop	200	-918	-4.58
	Cattle	113	-567	-5.03
	Swine	199	-1076	-5.4
	Dairy	185	-804	-4.35
AESA sub-basins	1	76	-386	-5.05
	13	296	-1270	-4.29
	24	177	-1018	-5.76
	25	177	-964	-5.44
	32	458	-1482	-4.06

Table 7.25. APEX estimated environmental results at the edge-of-field (subarea) within the Red Deer River study area for Scenario 7 (Wetland Restoration). The five AESA sub-basins are shown in bold.

Sub-basin	Modelled area (ha)	Percentage changes of flowTSS, and nutrient from baseline scenario[z]							
		Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
		(%)							
1	**35,394**	**-2.7**	**-17.4**	**48.5**	**128.3**	**-5.0**	**-4.7**	**26.7**	**10.6**
2	25,323	-1.1	-11.3	-8.7	40.6	-7.3	-4.5	-8.3	0.3
3	7,049	-1.2	0.0	-0.9	0.0	-2.3	-1.4	-1.3	-1.3
4	3,118	0.0[y]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	43,230	0.1	-0.7	-1.9	3.1	-1.1	-1.4	-1.7	-0.9
6	31,060	-3.7	-4.0	-8.9	-3.4	-4.8	-5.8	-7.2	-5.3
7	1,329	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	20,092	-4.1	-9.5	-8.7	11.9	-7.1	-7.1	-8.3	-4.3
9	708	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	55,995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	39,794	0.1	-5.4	-10.8	-3.6	-1.9	-2.4	-6.8	-2.4
12	44,768	-0.4	-0.3	-1.3	-0.6	-0.9	-1.0	-1.2	-1.0
13	**17,445**	**-2.8**	**-4.7**	**-1.8**	**-1.6**	**-0.7**	**-0.9**	**-0.9**	**-0.9**
14	20,514	-3.8	-6.7	6.5	13.8	-4.0	-4.1	2.8	-3.0
15	33,842	-11.2	-11.5	-12.1	-12.6	-10.7	-9.0	-11.6	-9.5
16	2,763	-3.3	-7.0	-2.2	-0.4	-20.5	-7.1	-4.5	-6.0
17	4,729	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	53,062	-3.4	-3.2	-3.5	-2.7	-4.2	-4.2	-3.7	-4.0
19	35,641	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	29,237	-0.7	-0.7	0.0	0.3	-1.2	-1.1	-0.2	-0.9
21	13,177	-13.1	-6.9	-18.2	-10.5	-13.5	-16.9	-16.7	-16.2
22	2,673	-5.6	-1.5	-1.5	0.4	-2.5	-1.9	-1.8	-1.7
23	13,496	0.1	-20.4	2.1	5.5	-1.8	0.1	0.9	0.5
24	**4,523**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
25	**15,379**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
26	66,468	-5.4	3.9	-11.9	-4.3	-11.0	-16.3	-11.6	-14.7
27	45,708	-17.3	-12.1	-21.0	-15.6	-24.0	-17.8	-21.8	-17.3
28	38,123	-5.1	-4.2	-7.7	-2.2	-8.9	-9.5	-8.1	-8.8
29	17,446	-2.5	-0.3	1.1	3.3	-4.6	-7.6	-1.1	-6.2
30	25,153	-6.8	-3.7	-11.5	-2.7	-12.5	-11.0	-11.8	-10.0
31	9,073	-3.0	-1.0	-4.5	-2.0	-4.5	-4.5	-4.5	-4.4
32	**5,796**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
33	38,032	-0.8	-4.1	5.2	7.4	-0.9	-0.7	3.5	0.6
34	65,215	-0.4	-0.3	-1.4	0.4	-2.7	-2.1	-2.0	-2.0
35	87,268	-2.2	0.8	-7.8	2.0	-6.2	-6.6	-7.0	-6.1
36	55,237	-2.6	-0.6	-3.7	0.6	-11.0	-15.3	-6.7	-13.2
37	60,650	-4.7	-5.5	-17.3	-10.3	-20.8	-25.4	-18.2	-20.7
38	19,016	-4.9	-1.4	2.7	6.5	-4.4	-6.9	1.0	-4.8
39	9,144	-2.6	-6.1	0.6	4.3	-1.3	-4.3	0.1	-3.0
40	9,817	-1.5	-0.3	-1.2	-0.5	-0.7	-1.8	-1.1	-1.6
41	81,397	-6.2	-9.9	-10.8	-3.5	-8.1	-11.0	-9.3	-10.7

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Zero value indicates that the BMP was not required in a particular sub-basin and the environmental indicators did not change.

As with most of the scenarios, the study area and sub-basin outlet impacts from the SWAPP model simulations largely mirrored the edge-of-field results from APEX (Table 7.26). As stated previously, this is primarily because the vast majority of land in each sub-basin was simulated in APEX. Consequently the study area-level and sub-basin-level impacts showed flow and TSS and soluble nutrient loss reductions and, with few exceptions, organic nutrient and total nutrient loss reductions as well.

The Scenario 7 cumulative effects showed small improvements to environmental indicators along the main stem of the RDR. The sub-basin and study area outlet impacts were predicated upon the path of surface water flow between sub-basins as well as inflow into the RDR from upstream of Sub-basin 17. The cumulative results at the study area outlet (Sub-basin 39) showed a reduction of about 0.5% for flow and export coefficients for TSS. In addition, the export coefficients for TN and TP decreased by 1.8 and 3.8%, respectively (Table 7.26). As is the case for the other scenarios, the magnitudes of the flow, TSS, and nutrient reductions for the wetland restoration scenario were dampened by the fact that most of the flow at the outlet of the RDR study area was from the upper RDR watershed, upstream from the RDR study area inlet (Sub-basin 17).

Scenario 7 resulted in a reduction in net returns (Table 7.27), which was similar to other structural BMPs that take land out of crop production. Overall, the predicted average cost for restoring wetlands was \$3.77 ha^{-1} yr^{-1} for the RDR study area. The primary economic impact reflects the opportunity cost incurred by farmers, which is the agricultural profit forgone because of land placed in wetland restoration. The costs represented in Scenario 7 also include an initial capital outlay for establishing the wetland. The predicted economic impacts on a per hectare basis were similar among farm types, farm sizes, and sub-basins.

Table 7.26. SWAPP estimated cumulative changes at the outlets of each sub-basin for Scenario 7 (Wetland Restoration). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Percentage changes of flow, TSS, and nutrient from baseline scenario[z]							
	Individual	Cumulative		Depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	------- (ha) -------			---------------------------------- (%) ----------------------------------							
17	4,729	1,164,729[y]		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	35,641	35,641	Tr.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	6,541	1,206,912		0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
1	35,394	35,394	Tr.2.2.2	-2.7	-17.4	48.7	127.0	-5.0	-0.6	24.0	10.1
2	25,323	25,323	Tr.2.2.1	-1.1	-10.2	-8.7	40.1	-7.3	-3.2	-8.3	0.1
5	43,230	103,947	Tr.2.2	-1.8	-8.6	16.9	53.1	-4.1	0.2	8.8	3.6
8	29,263	29,263	Tr.2.1.1	-4.1	-9.5	-8.7	11.8	-7.1	-6.3	-8.3	-4.4
9	708	29,971	Tr.2.1	-4.0	-10.3	-7.2	9.7	-9.0	-5.0	-7.5	-3.9
12	44,768	178,686	Tr.2	-1.7	-6.6	10.8	34.6	-3.7	0.4	5.1	2.2
20	29,238	1,414,835		-0.1	-0.3	0.8	4.9	-0.3	0.4	0.3	0.9
18	53,062	1,467,897		-0.1	-0.3	0.7	4.4	-0.4	0.1	0.2	0.5
13	17,445	17,445	Tr.3	-2.8	-4.4	-1.8	-1.7	-0.7	-0.9	-0.9	-0.9
14	20,514	1,505,856		-0.1	-0.2	0.7	4.7	-0.4	0.0	0.1	0.3
3	7,049	7,049	Tr.4.1.1.1.1.1	-1.3	-0.1	-0.9	0.0	-2.3	-1.4	-1.4	-1.3
4	3,118	10,167	Tr.4.1.1.1.1	-0.8	-0.2	-0.5	0.0	-1.6	-1.0	-0.9	-0.9
11	39,794	49,961	Tr.4.1.1.1	0.0	-4.5	-8.5	-3.1	-2.0	-2.1	-5.6	-2.2
6	31,060	81,020	Tr.4.1.1	-1.1	-4.1	-8.7	-3.3	-2.5	-2.5	-5.7	-2.5
7	1,329	82,349	Tr.4.1	-1.1	-3.5	-7.5	-2.9	-2.6	-2.5	-5.6	-2.5
10	72,691	155,040	Tr.4	-1.1	-2.1	-6.9	-2.9	-2.7	-2.5	-5.8	-2.5
15	33,842	33,842	Tr.5	-11.2	-11.6	-12.0	-12.5	-10.7	-9.1	-11.5	-9.5
26	66,468	1,761,206		-0.1	-0.2	0.0	2.6	-0.6	-1.4	-0.4	-1.2
21	13,177	13,177	Tr.6.1.1	-13.2	-7.2	-18.4	-10.8	-13.5	-16.7	-16.7	-16.3
22	2,673	15,850	Tr.6.1	-11.9	-6.2	-14.8	-9.1	-10.4	-13.7	-13.4	-13.5
27	45,708	61,558	Tr.6	-15.4	-13.7	-19.0	-14.3	-18.7	-15.4	-18.9	-15.3
30	25,153	25,153	Tr.7	-6.7	-4.7	-11.5	-2.6	-12.5	-10.7	-11.8	-10.0
33	38,032	1,885,950		-0.2	-0.3	-0.5	1.6	-0.9	-2.2	-0.7	-2.1
24	4,523	4,523	Tr.8.2.2.1.1.1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	15,379	19,902	Tr.8.2.2.1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	17,446	37,348	Tr.8.2.2.1	-0.8	-0.5	0.8	2.6	-1.4	-2.7	-0.6	-2.5
31	9,073	46,422	Tr.8.2.2	-1.0	-1.1	-0.3	1.3	-1.6	-3.0	-1.1	-2.8
32	5,796	5,796	Tr.8.2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	55,237	107,454	Tr.8.2	-1.7	-1.9	-2.6	0.7	-5.5	-7.8	-4.2	-7.3
23	13,496	13,496	Tr.8.1.1	0.1	-18.0	2.1	5.5	-1.7	0.2	0.7	0.5
28	38,123	51,619	Tr.8.1	-3.8	-4.8	-4.4	-0.2	-7.5	-5.5	-5.6	-5.2
37	60,650	219,724	Tr.8	-3.0	-3.7	-9.3	-4.9	-8.9	-9.1	-9.1	-8.8
38	19,016	2,124,690		-0.4	-0.5	-1.8	0.1	-1.8	-3.9	-1.8	-3.8
34	65,215	65,215	Tr.9.1.2	-0.4	-0.5	-1.4	0.4	-2.6	-2.1	-2.0	-2.0
35	87,268	87,268	Tr.9.1.1	-2.2	0.4	-7.7	2.0	-6.2	-6.5	-6.9	-6.2
41	81,397	233,880	Tr.9.1	-2.7	-3.6	-6.5	-0.6	-5.8	-6.2	-6.1	-6.0
40	9,817	243,698	Tr.9	-2.7	-3.7	-5.5	-0.5	-5.5	-6.0	-5.5	-5.9
39	**9,144**	**2,377,531**		**-0.4**	**-0.5**	**-1.7**	**0.2**	**-1.8**	**-3.9**	**-1.8**	**-3.8**

[z] Depth = runoff depth, TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphor us.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Table 7.27. Change in annual net returns for the Scenario 7 (Wetland Restoration) relative to the baseline scenario.

		Average size (ha)	Total net return ($ yr^{-1})	Total net return ($ $\text{ha}^{-1}\,\text{yr}^{-1}$)
Red Deer River study area		177	-649	-3.77
Farm size class	Small	122	-539	-4.43
	Medium	174	-584	-3.36
	Large	454	-1458	-3.21
Farm type	Crop	200	-734	-3.66
	Cattle	113	-446	-3.96
	Swine	199	-912	-4.58
	Dairy	185	-638	-3.46
AESA sub-basins	1	76	-329	-4.30
	13	296	-964	-3.25
	24	177	-798	-4.52
	25	177	-775	-4.37
	32	458	-1155	-3.17

7.4.8 Comparing Environmental and Economic Impacts

Graphical comparisons of environmental indicator (TSS, flow, TN, and TP) and farm profit changes relative to baseline conditions are shown in Figures 7.2 through 7.5. For the RDR study area (Figure 7.2), Scenario 3 (rotational grazing) was the only scenario that was in the bottom-right quadrant for all four environmental indicators. This quadrant represents an improvement in environmental quality combined with increased farm profits. As mentioned previously, rotational grazing entails better management of pastured livestock leading to improved forage production and reduced feed costs, which was the main reason for the economic benefit predicted for Scenario 3. Scenario 2 (manure P management) was also in this quadrant for TN and TP, but with less profit gain compared to Scenario 3. Of the scenarios that resulted in the largest reduction in farm profits, Scenario 6 (riparian management) had the greatest reduction in water quality parameters. Scenarios 5 and 7 (grassed waterways and wetland restoration) had the second highest reduction in farm profits and with often the least improvement in water quality parameters. Scenario 4 (seasonal bedding) had modest improvements at a modest cost. It is quite noticeable that most of the scenarios, including wetland restoration in particular, did not result in sizable flow reductions at the outlet of the sub-basins and the entire study area. As explained in the limitations Sub-section 4.8, this is partly due to the fact that a large wetland existing at the outlet of each sub-basin was already acting as a retention structure, resulting in significant reductions in upstream flow, sediment, and nutrients, regardless of the upstream BMPs.

It should be noted that the reductions in flow and TSS parameters were typically well less than 1.6%. The largest reduction occurred for Scenario 2 with a predicted reduction of about 28.2% in TP at the outlet of the RDR study area. It is interesting the model predicted \$0.42 ha^{-1} yr^{-1} farm profit for this scenario. It is generally believed that adopting a P-based management for manure to meet crop P requirements will require that manure is spread on a larger land base resulting in increased hauling costs.

Figures 7.3 through 7.5 show the results for three of the five AESA sub-basins (Sub-basins 1, 13, and 24). Results for AESA Sub-basins 25 and 32 were generally similar to Sub-basins 13 and 24, and thus were not shown here to avoid redundancy. For all AESA Sub-basins, Scenario 3 was the only scenario that had positive economic benefits, while also demonstrating different levels of environmental benefits. For the three AESA Sub-basins shown, the increase in farm profits for Scenario 3 ranged from \$1.03 ha^{-1} yr^{-1} for Sub-basin 24 to \$11.48 ha^{-1} yr^{-1} for Sub-basin 1. The change in the environmental indicators was similar among the three AESA Sub-basins, except for smaller reductions in Sub-basin 24 for flow depth and TSS. Most of the other scenarios showed modest changes in environmental indicators at a modest cost. The only noteworthy exceptions were the somewhat higher costs to achieve reductions in most environmental indicators for Scenarios 2 and 6.

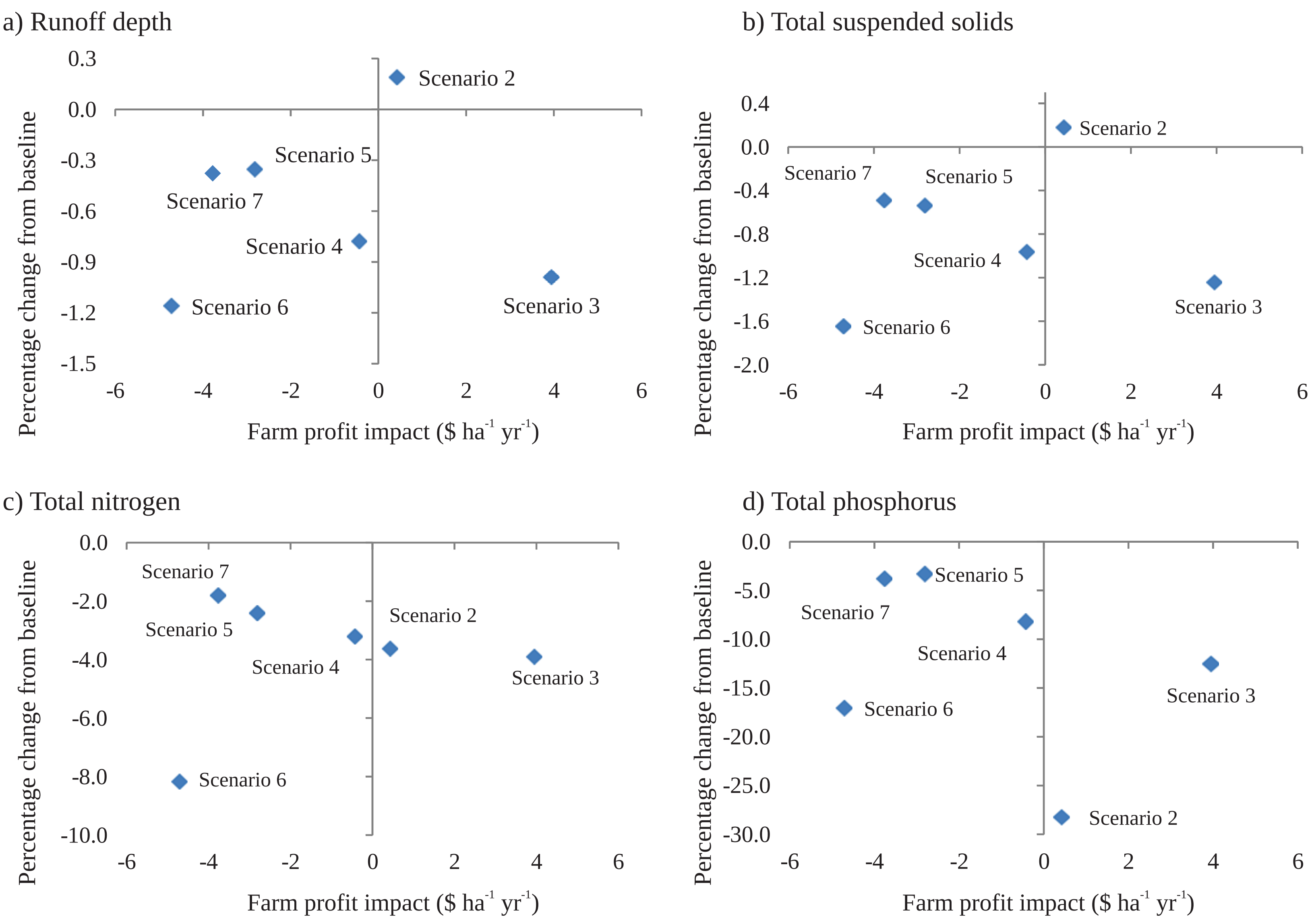

Figure 7.2. Impacts of scenarios on farm profits and (a) runoff depth, (b) total suspended solids, (c) total nitrogen, and (d) total phosphorus for the Red Deer River study area. Total suspended solids, total nitrogen, and total phosphorus were expressed as export coefficients.

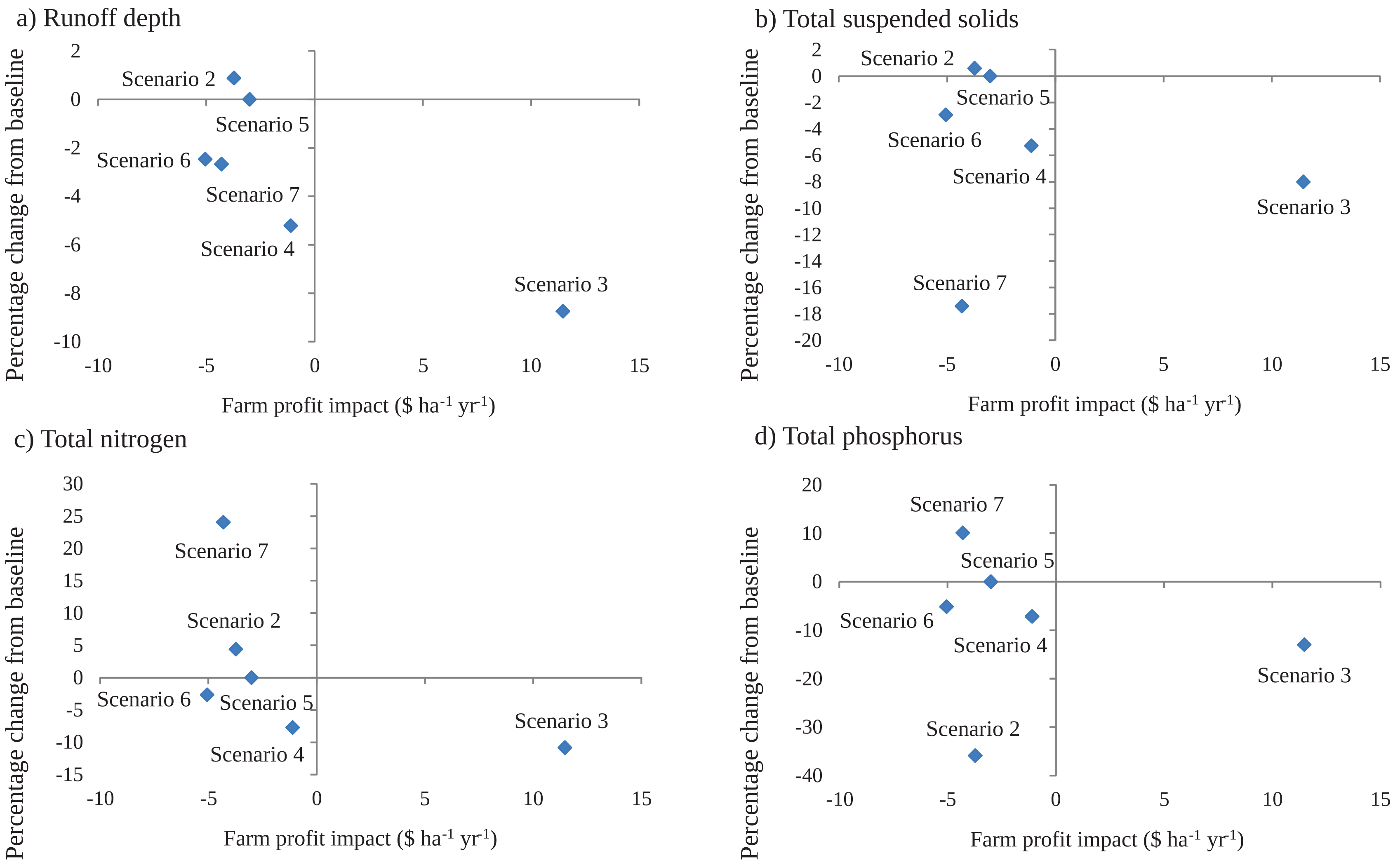

Figure 7.3. Impacts of scenarios on farm profits and (a) runoff depth, (b) total suspended solids, (c) total nitrogen, and (d) total phosphorus for AESA Sub-basin 1. Total suspended solids, total nitrogen, and total phosphorus were expressed as export coefficients.

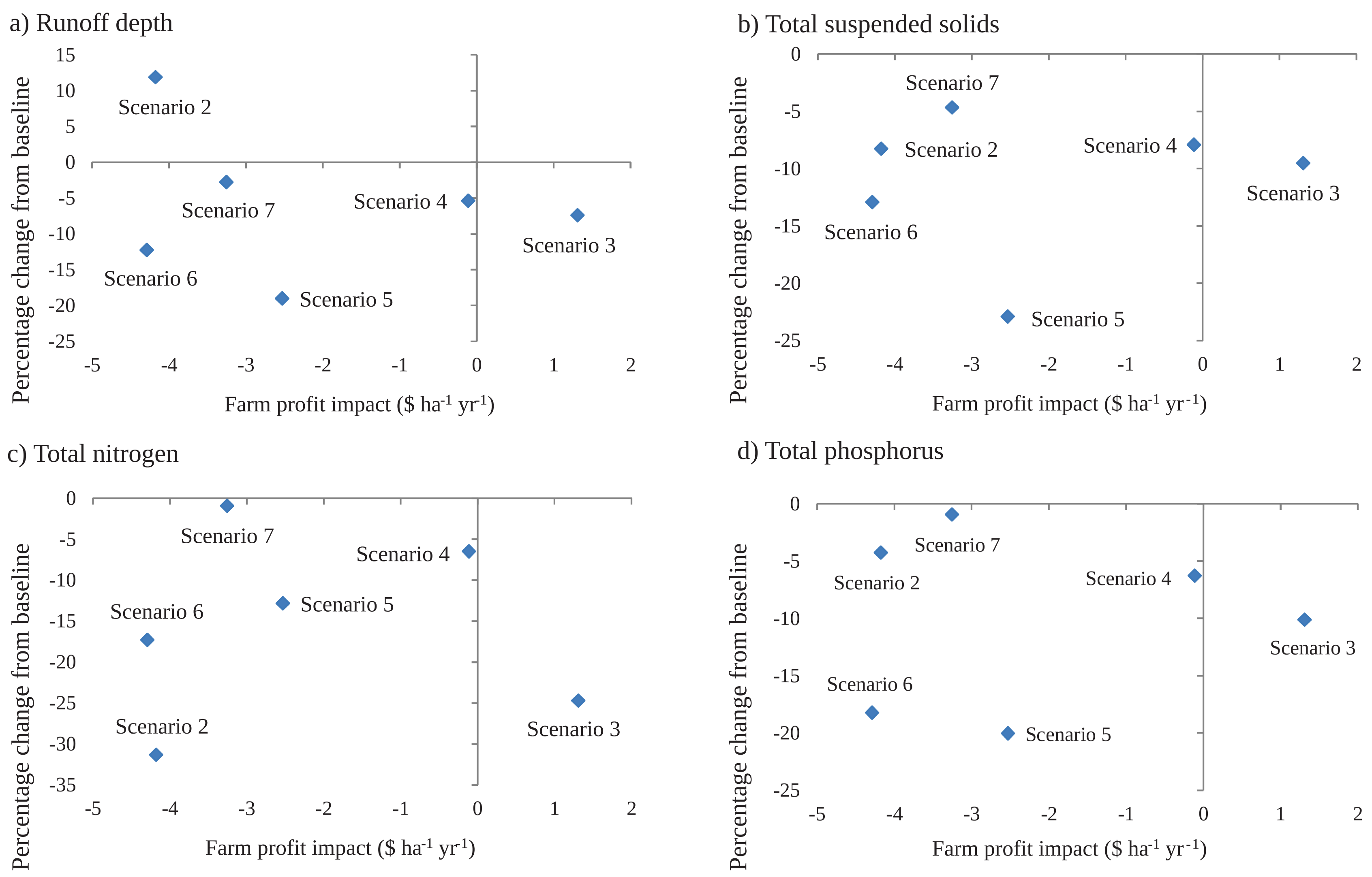

Figure 7.4. Impacts of scenarios on farm profits and (a) runoff depth, (b) total suspended solids, (c) total nitrogen, and (d) total phosphorus for AESA Sub-basin 13. Total suspended solids, total nitrogen, and total phosphorus were expressed as export coefficients.

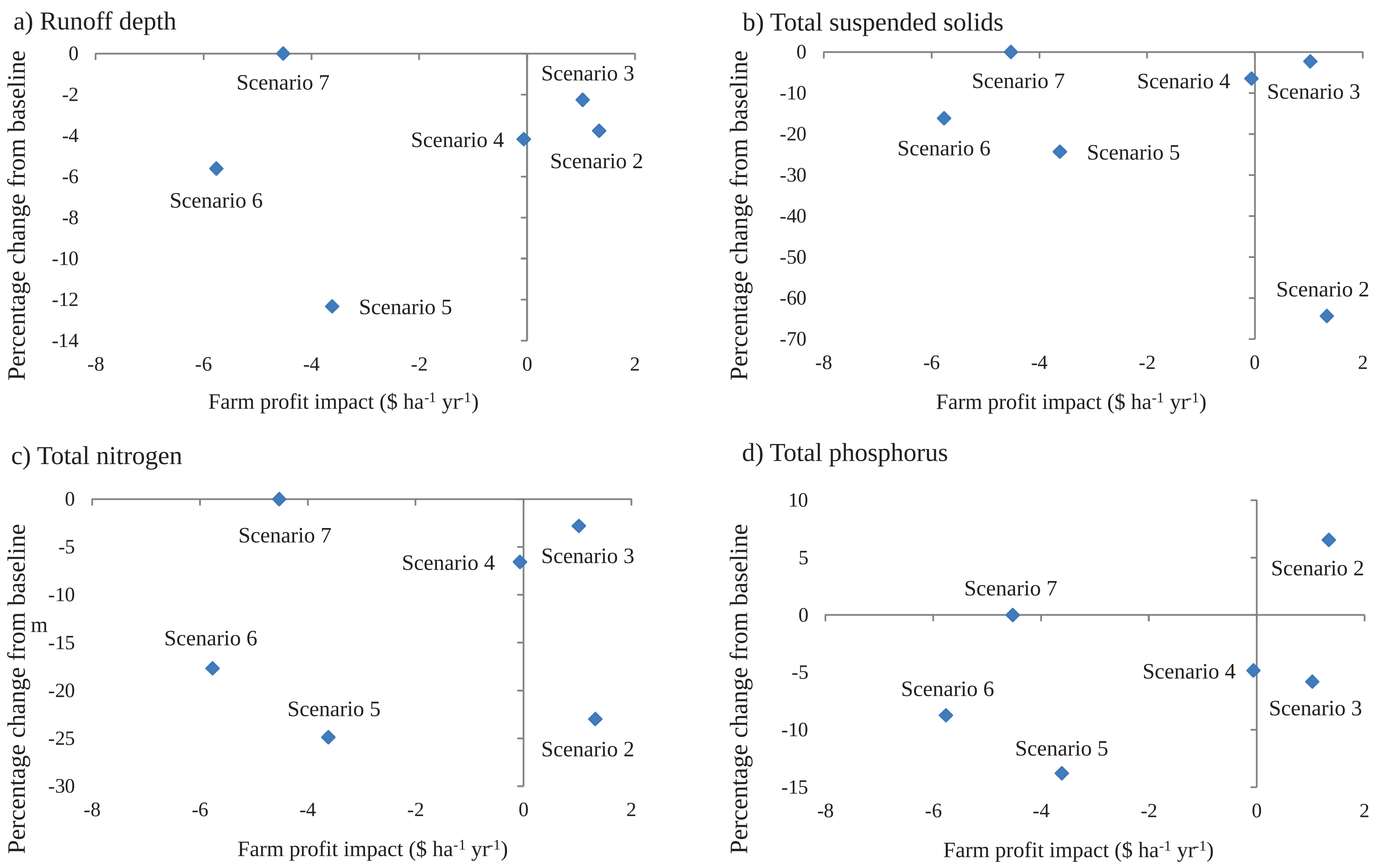

Figure 7.5. Impacts of scenarios on farm profits and (a) runoff depth, (b) total suspended solids, (c) total nitrogen, and (d) total phosphorus for AESA Sub-basin 24. Total suspended solids, total nitrogen, and total phosphorus were expressed as export coefficients.

7.4.9 Cost-Effectiveness of BMP Scenarios

In general, cost-effectiveness calculations indicate how much it costs to obtain one unit improvement in an environmental indicator. However, cost-effectiveness calculations are also applied to project scenarios that show economic gains rather than economic costs (reduced profits). Consequently, the sign of a cost-effectiveness value has a different meaning depending on whether it represents a scenario cost or benefit. For scenarios resulting in reduced farm profits, cost-effectiveness values with a positive sign represent an improvement in the environmental indicator while a negative sign corresponds to deterioration in the environmental indicator. It is the opposite for scenarios resulting in improved farm profits. Cost-effectiveness values with a positive sign represent deterioration in the environmental indicator while a negative sign corresponds to an improvement in the environmental indicator.

Table 7.28 shows the cost-effectiveness values of various scenarios for the RDR study area. Scenarios 2 and 3 had positive economic benefits (indicated by the + sign at the end of the scenario name). In this situation, the environmental indicator cost-effectiveness values with negative signs represent the economic benefits associated with one unit improvement in the environmental indicator (highlighted in green). Scenario 3 had economic gains and environmental improvements for all of the indicators, so it is the most cost effective scenario. For example, reductions in TN were accompanied by an increase in net farm profits of \$246 kg^{-1} reduction in TN. Scenario 2 had mixed results, with environmental improvements for five of the indicators, but had worse performance for two of the environmental indicators (TSS and ON; highlighted in purple). For ON, farm profit increased by \$282 for each kilogram increase of ON.

Table 7.28. Cost effectiveness of alternative beneficial management practice scenarios for the Red Deer River study area.[z]

BMP scenario[y]	TSS ($ Mg^{-1})	Organic N	Organic P	NO_3-N	PO_4-P	Total N	Total P
		-----------------	-----------------	($ kg^{-1})	-----------------	-----------------	-----------------
Scenario 2 +[w]	479	282	-747	-26	-4	-28	-4
Scenario 3 +	-655	-599	-6,037	-417	-80	-246	-79
Scenario 4	94	165	1,914	42	14	34	13
Scenario 5	1086	743	8,614	445	219	278	214
Scenario 6	591	398	3,993	214	71	139	69
Scenario 7	1592	1579	-260,907	7278	250	498	250

[z] Cost-effectiveness ratios were computed as change in net farm returns divided by change in relevant environmental indicator. Thus when the change in the environmental indicator was 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 = Manure Management; Scenario 3 = Rotational Grazing; Scenario 4 = Seasonal Bedding; Scenario 5 = Grassed Waterways; Scenario 6 = Riparian Setbacks; Scenario 7 = Wetland Restoration.

[x] Negative values highlighted in green indicate a decrease in cost accompanying an improvement in the environmental indicator, while negative values highlighted in red indicate an increase in cost accompanying a deterioration in the environmental indicator.

[w] + = positive economic benefit.

Excluding Scenario 3, Scenario 4 was most cost-effective for improvements in TSS, and organic N (highlighted in blue). It was also relatively low cost for the other environmental indicators, so it is one of the most cost-effective scenarios. For example, farm profits decreased by $94 for each Mg decrease in TSS, while for the other scenarios farm profits decreased by $600 or more per Mg decrease of TSS.

The wetland restoration scenario (Scenario 7) was the least cost-effective, with the highest cost per unit improvement for most of the environmental indicators (highlighted in yellow). This scenario was especially poor in terms of changes in OP levels. Since the scenario had an overall cost increase for implementation, the negative sign indicates in this case that it resulted in a worse environmental performance as well (highlighted in red). However, the magnitude of the cost-effectiveness value is very large because the magnitude of the increase in OP (the denominator) was very small.

Table 7.29 shows cost-effectiveness values for three of the AESA Sub-basins; 1, 13, and 24. Results for the other two AESA sub-basins were excluded to avoid redundancy of the discussion. As with the overall study area (Table 7.28), Scenario 3 was the most cost-effective for each of the AESA sub-basins, demonstrating economic gains accompanied by improvements to each environmental indicator.

Results for the remaining scenarios were more varied. For Scenario 2, Sub-basin 24 had economic gains as did the overall study area, while costs were incurred for Sub-basins 1 and 13. Consequently, the negative signs are interpreted differently.

For Scenario 2, each AESA sub-basin had improvements and deteriorations in environmental indicators, as did the overall study area, but the pattern varied between the indicators. For example, Sub-basin 1 had deterioration in TSS similar to the overall study area, but Sub-basins 13 and 24 showed improvements in TSS. Therefore, the overall cost-effectiveness for ASEA sub-basins was similar to the overall study area, but performance of individual indicators varied from one sub-basin to another.

As with the overall study area, when Scenarios 2 and 3 were excluded, Scenario 4 was most cost-effective, demonstrating the lowest cost increases for practically all of the environmental indicators for each AESA sub-basin.

The wetland restoration scenario (Scenario 7) was again the least cost-effective for the two sub-basins that implemented this BMP, with the highest cost per unit improvement for most of the environmental indicators. In Sub-basin 1, the reduced farm profits were accompanied by deterioration in four environmental indicators.

In summary, cost-effectiveness calculations provide a sense of the overall performance of BMP scenarios. In addition, they provide the relative performance of each environmental indicator, so specific BMP projects or combination of projects can be identified to target specific environmental needs or objectives.

Table 7.29. Cost-effectiveness of alternative scenarios in AESA Sub-basins 1, 13, and 24.

	TSS	Organic N	Organic P	NO_3-N	PO_4-P	Total N	Total P
BMP scenario[z]	(\$ Mg^{-1})	------------------------------------ (\$ kg^{-1}) ------------------------------------					
			AESA Sub-basin 1				
Scenario 2	-11,054	-42	2659	64	13	-123	13
Scenario 3 +[w]	-2,519	-311	-1271	-301	-120	-153	-110
Scenario 4	366	50	308	35	20	21	19
Scenario 5	na	na	na	na	na	na	na
Scenario 6	3,020	-218	-1293	121	111	274	121
Scenario 7	434	-24	-50	272	995	-26	-53
			AESA Sub-basin 13				
Scenario 2	15,387	-87	-730	21	217	27	308
Scenario 3 +	-4,268	-262	-1,750	-11	-42	-11	-41
Scenario 4	432	25	257	4	6	3	6
Scenario 5	3,407	-644	-3,835	38	39	40	40
Scenario 6	10,239	324	2,647	60	76	50	74
Scenario 7	21,503	2127	15,184	1106	1174	728	1090
			AESA Sub-basin 24				
Scenario 2 +	-296	48	-1718	-13	53	-17	55
Scenario 3 +	-6445	-691	-4576	-132	-48	-111	-47
Scenario 4	129	18	125	3	3	3	3
Scenario 5	2,117	399	3410	49	71	43	70
Scenario 6	5081	389	2543	130	189	97	176
Scenario 7	na	na	na	na	na	na	na

[z] Scenario 2 = manure management; Scenario 3 = rotational grazing; Scenario 4 = seasonal bedding; Scenario 5 = grassed waterways; Scenario 6 = riparian setbacks; Scenario 7 = wetland restoration.

[y] Negative values highlighted in green indicate a decrease in cost accompanying an improvement in the environmental indicator, while negative values highlighted in red indicate an increase in cost accompanying a deterioration in the environmental indicator.

[x] na = not applicable.

[w] + = positive economic benefit.

7.4.10 Economic Results at the Study Area Level

To this point, the economic results have only been presented at the farm level on a per hectare basis. In Table 7.30, the economic impact is pro-rated to the study area level. For example, the 112 crop farms developed for the FEM analysis (Table 3.1) represent 2998 crop farms in the study area. In the baseline scenario, those farms were projected to earn \$84,030,065 yr^{-1} in total net returns. The study area net returns for all farms totalled \$144,445,052 yr^{-1}.

The total net returns and the change in total net returns for the study area farms for each BMP scenario are presented in Table 7.31. The largest gain in net returns was for Scenario 3 as a result of improved forage production and reduced feed costs due to rotational grazing. This BMP was predicted to increase total farm net incomes by \$3,259,641 yr^{-1}. Scenarios 5, 6, and 7 were predicted to reduce total farm net returns by about \$2 to \$4 million yr^{-1}.

Table 7.30. Total number of farms represented in the study Red Deer River study area and the baseline total net returns by farm type.

Farm type	Number of farms	Total net returns of study area farms (\$ yr^{-1})
Crop	2998	84,030,065
Cattle	1541	15,705,914
Swine	206	33,685,713
Dairy	55	10,325,892
Turkey	2	697,468
Total	4802	144,445,052

Table 7.31. Total net returns and change in total net returns for the Red Deer River study area farms by BMP scenario.

BMP scenario^z	Total net returns of farms (\$)	Change in total net returns of farms (\$ yr^{-1})
Scenario 2	144,794,289	349,237
Scenario 3	147,704,693	3,259,641
Scenario 4	144,084,029	-361,023
Scenario 5	142,115,093	-2,329,959
Scenario 6	140,547,025	-3,898,027
Scenario 7	141,329,387	-3,115,665

^{z} Scenario 2 = manure management; Scenario 3 = rotational grazing; Scenario 4 = seasonal bedding; Scenario 5 = grassed waterways; Scenario 6 = riparian setbacks; Scenario 7 = wetland restoration.

7.4.11 Baseline and BMP Scenario Manure Hauling Characteristics

For each representative farm in the FEM, manure production quantities were calculated based on livestock inventories and feeding characteristics. The FEM also assessed each representative farm to determine whether a sufficient land base was available on-farm to accommodate the manure production. If not, FEM calculated how much manure had to be hauled off-farm. It also calculated the associated costs of the manure hauling operation.

Table 7.32 shows the manure hauling statistics for the study area farms in the baseline scenario. The statistics were based on the results of the 486 FEM representative farms pro-rated to the 4802 study area farms. The medium dairy farms required the highest proportion of manure hauling off-farm, at about 92% of total manure produced. However, there was only one dairy farm modelled in the study area. Swine farms were also shown to require high proportions of manure hauling off-farm, ranging from 62 to 85% of total manure produced. Furthermore, a large proportion of the medium and large swine farms were required to haul manure off-farm (64 and 86%, respectively). Small and medium sized cattle farms were required to haul a somewhat smaller proportion, at about 55% of total manure production. Since the number of cattle farms was much higher, they accounted for the majority of manure hauled. Recall that no large cattle farms were in the study area.

For the RDR study area as a whole, the analysis suggests that 511 of the 4802 farms (10.6%) are required to haul manure off-farm, and the hauling rate was 58.6% (Table 7.32). Over half of the study area farms were crop farms, and the small cattle farms were mixed farms with cropland.

The following analysis assesses the impact of the six BMP scenarios on the manure hauling needs of two groups of study area farms: those that hauled manure in the baseline scenario, and those that did not. Table 7.33 shows the impact of the BMP scenarios on the 511 farms in the study area that hauled manure in the baseline scenario. The results are the incremental increase in manure hauling requirements off-farm for these farms as a result of the BMP scenarios.

Table 7.32. Number of study area farms that hauled manure off-farm in the baseline scenario and the proportion hauled off-farm.

Farm Type	Farm size	Number of farms hauling manure	% of farms that hauled manure	% of manure hauled off-farm
Beef	Small	117	14.3	54.4
	Medium	338	46.8	57.7
Swine	Small	4	3.1	85.2
	Medium	45	64.3	72.3
	Large	6	85.7	62.2
Dairy	Small	0	na[z]	na
	Medium	1	1.9	91.6
	Large	0	na	na
Turkey	Medium	0	na	na
Total		511	10.6	58.6

[z] na = not available.

Not surprisingly, the manure management scenario (Scenario 2) had the largest impact on off-farm manure hauling requirements, increasing by 24.6 percentage points to a total of 83.1% of all manure produced. Scenarios 5, 6, and 7 each required the restriction of manure applications on various landforms. Consequently, the manure that had been applied to these areas was hauled off-farm. Since these areas were small compared to the total farm land base, it resulted in only 0.8 to 1.1 percentage points increase in manure hauling.

Table 7.34 is an assessment of the impact of the six BMP scenarios on the manure handling characteristics of the 4291 farms in the study area that FEM did not require to haul manure off-farm in the baseline scenario. Scenario 2 (manure agronomic phosphorus management) had the largest impact on these farms. Under this scenario, an additional 759 farms were required to haul manure off-farm. The average amount of manure hauled from these farms was 30.8%. This percentage is less than for the farms that were hauling manure off-farm in the baseline scenario (Table 7.32). Again, Scenarios 5, 6, and 7 resulted in more manure hauling. Specifically, 78 farms that did not haul manure in the baseline scenario were required to haul manure off-farm after the introduction of the BMP. It should be noted that FEM indicated that only one representative farm began to haul manure as a result of these BMPs. However, that representative farm had a high weighting of 78. This means that this single representative farm is projected to 78 farms in the study area.

Table 7.33. Average increase in the percentage of manure hauled off-farm for farms that hauled manure off-farm in the baseline scenario.

BMP scenario[z]	Number of farms hauling manure	% of manure hauled off-farm	% change due to the BMP scenario
Scenario 2	511	83.1	24.6
Scenario 3	511	58.6	0.0
Scenario 4	511	58.6	0.0
Scenario 5	511	59.3	0.8
Scenario 6	511	59.9	1.1
Scenario 7	511	59.3	0.8

[z] Scenario 2 = manure management; Scenario 3 = rotational grazing; Scenario 4 = seasonal bedding; Scenario 5 = grassed waterways; Scenario 6 = riparian setbacks; Scenario 7 = wetland restoration.

Table 7.34. Increase in the number of study area farms that hauled manure in the BMP scenarios and the average proportion hauled.

BMP scenario[z]	Number of farms hauling manure off-farm	Increase in number of farms from baseline	% of manure hauled off-farm
Scenario 2	1270	759	30.8
Scenario 3	511	0	na[y]
Scenario 4	511	0	na
Scenario 5	589	78	1.0
Scenario 6	589	78	1.4
Scenario 7	589	78	1.0

[z] Scenario 2 = manure management; Scenario 3 = rotational grazing; Scenario 4 = seasonal bedding; Scenario 5 = grassed waterways; Scenario 6 = riparian setbacks; Scenario 7 = wetland restoration.
[y] na = not available.

7.4.12 Identification of RDR Study Area Critical Source Areas

Earlier studies indicate that a relatively small portion of a watershed area (i.e., critical source areas) can produce a majority of TSS and nutrients loads (Meals and Budd 1998, Pionke et al. 2000). In general, critical source areas (CSAs) are identified where the landscape conditions are favourable for generating high amounts of surface flow, TSS, and nutrients. Researchers used different approaches to establish threshold values in order to identify CSAs. For example, O'Donnell et al. (2011) and Mudgal et al. (2011) used SWAT- and APEX-estimated loads, respectively; whereas, Meals and Budd (1998) used observed export coefficient and loading functions.

For the RDR study area, the CSA analyses were completed at the sub-basin and subarea scales using APEX-estimated annual average values for sediment and nutrient export coefficients under the baseline scenario. The unit-area load contributions were functions not only of the biophysical attributes of the landscape but also of the management practices used on the fields in the respective sub-basins and subarea polygons. The sub-basin scale coefficients represent cumulative sediment and nutrient losses from all subareas in the sub-basins after being routed through downstream wetlands in each sub-basin. Conversely, the subarea scale coefficients were estimated for individual subareas and showed total loads transported to the outlet-edge of each subarea polygon. In general, the sub-basin scale coefficients were lower than the subarea values due to routing effects of subarea polygons within each sub-basin.

In this report, the sub-basin coefficients were used to represent graphically (i.e., maps) CSAs among 41 sub-basins and the subarea coefficients were used to estimate a relative contribution of loads from CSAs within the RDR study area. Mapping of subarea level coefficients was beyond the scope of this study due to the lack of information of spatial distribution of subarea polygons. A possible resolution to this issue would have been to define smaller and spatially more refined sub-basins areas. However, this would have resulted in a significant increase in computational requirements.

The CSA analyses were completed for seven environmental indicators: TSS, ON, OP, NO_3-N, PO_4-P, TN, and TP. The APEX indicators were grouped into five risk categories: Very Low, Low, Moderate, High, and Very High. The minimum and maximum range of values for these categories were calculated using standard deviations of variation around mean values estimated for the RDR sub-basins (Table 7.35). Based on the distributions of the selected indicators, the categories were based on incremental groups, each approximately one standard deviation in range from the mean value of the indicator for the entire study area. Ultimately, these values were used to generate maps, which identified the CSAs at the sub-basin scale within the RDR study area.

The risk categories for all of the sub-basins for the seven environmental indicators are illustrated in Figures 7.6 and 7.7. Dark green represents sub-basins with Very Low risk ratings while red represents sub-basins with Very High risk ratings. In this assessment, the CSAs were sub-basins classified as either High or Very High risk (i.e., $> \mu + 0.5\sigma$).

Table 7.35. The sub-basin scale estimated range of values for selected risk categories and the selected environmental indicators.

Risk category	Threshold min. and max. values defined[z]	Range of values estimated for environmental indicators[y]						
		TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
		(Mg ha^{-1})	---------------------------- (kg ha^{-1}) ----------------------------					
Very Low	$\leq \mu - 1.5\sigma$	< 0.001	< 0.024	< 0.007	< 0.001	< 0.086	< 0.071	< 0.105
Low	$> \mu - 1.5\sigma$ and $\leq \mu - 0.5\sigma$	0.001 - 0.012	0.024 - 0.132	0.007 - 0.027	0.001 - 0.063	0.086 - 0.252	0.071 - 0.217	0.105 - 0.282
Moderate	$> \mu - 0.5\sigma$ and $\leq \mu + 0.5\sigma$	0.012 - 0.022	0.132 - 0.240	0.027 - 0.046	0.063 - 0.145	0.252 - 0.417	0.217 - 0.363	0.282 - 0.460
High	$> \mu + 0.5\sigma$ and $\leq \mu + 1.5\sigma$	0.022 - 0.033	0.240 - 0.349	0.046 - 0.066	0.145 - 0.227	0.417 - 0.583	0.363 - 0.509	0.460 - 0.637
Very High	$> \mu + 1.5\sigma$	> 0.033	> 0.349	> 0.066	> 0.227	> 0.583	> 0.509	> 0.583

[z] μ = mean, σ = standard deviation.

[y] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

The risk categories among AESA sub-basins (Sub-basins 1, 13, 24, 25, and 32) varied considerably depending on the environmental indicator. Only Sub-basin 1 was classified in the Very High risk category for all environmental indicators (Figures 7.6 and 7.7). This is not a surprise considering that Sub-basin 1 runoff yield was very high (about 62 mm), almost twice as high as the runoff yield in Sub-basin 24. In addition, Sub-basins 13, 24, and 25 showed very high risk potential only for NO_3-N export, and Sub-basins 25 and 32 had high risk potential for the export of PO_4-P and NO_3-N, respectively. This assessment indicates that Sub-basin 1 should have the highest priority among the AESA sub-basins when implementing future BMPs.

The risk category analyses of subarea-scale polygons showed that the extent of CSAs varied with environmental indicator and ranged from 8% for TSS to 37% for TP of the total RDR study area (Table 7.36). The corresponding projected environmental contribution from these areas ranged from 49% for TN to 82% for TSS of total load yields from the RDR study area. For each environmental indicator, the proportion of environmental contribution was higher compared to the proportion of the critical source area within the study area (Table 7.36). This supports that CSAs contribute a relatively higher proportion of nutrient and sediment loss compared to areas at lower risk within watersheds. In the current study, it was estimated that 12% and 37% of total RDR study area exported 49% and 74% of TN and TP, respectively. When averaged among all seven environmental indicators, the CSA was 20% of the total RDR study area; whereas, the CSA contributed 65% of the total load of the environmental indicators (Table 7.36). This suggests that directing BMPs to the CSAs would likely have a relatively larger positive effect on water quality compared to areas of lower risk.

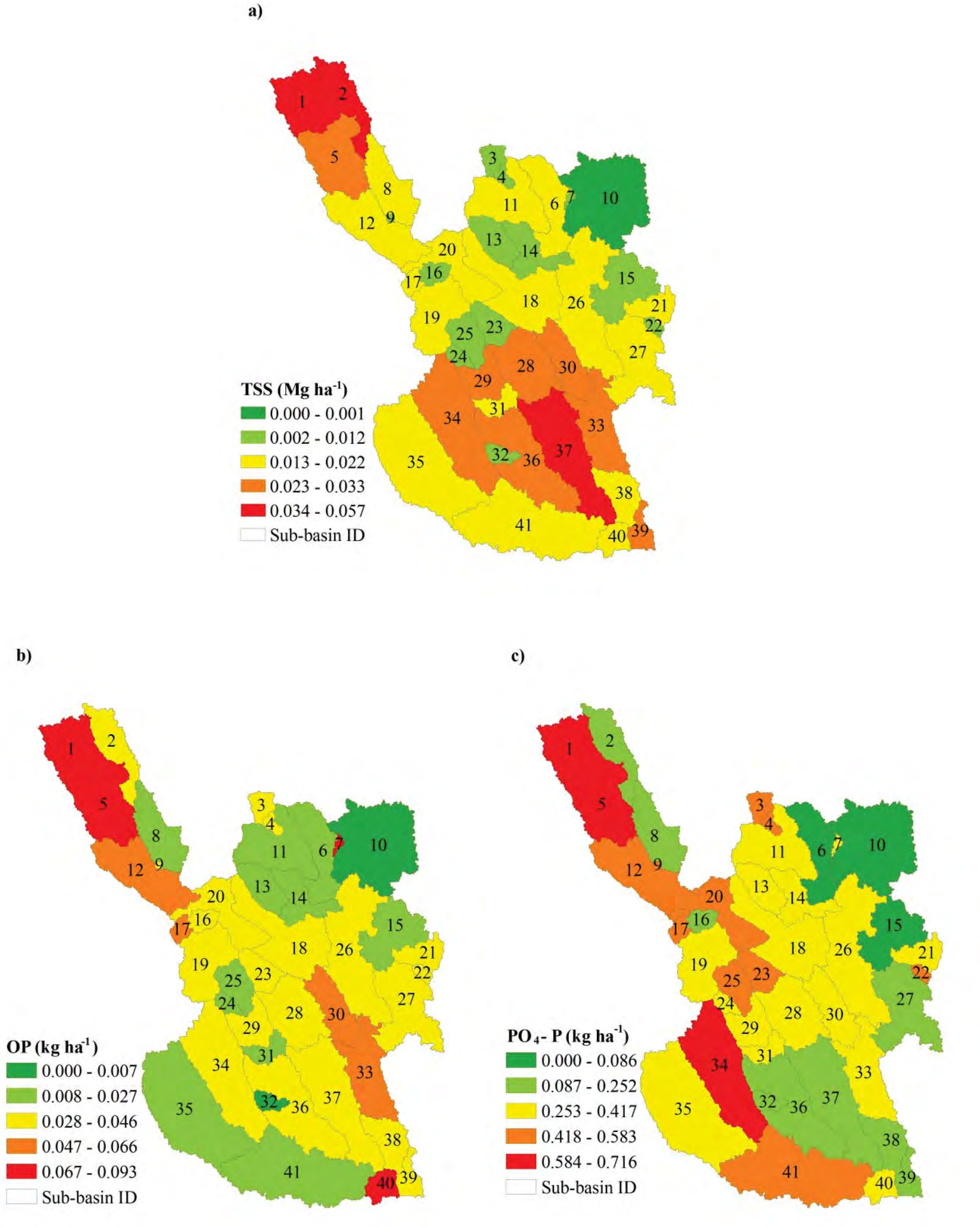

Figure 7.6. Sub-basin scale maps of export coefficients (a) TSS (total suspended solids), (b) OP (organic phosphorus), and (c) PO$_4$-P (phosphate phosphorus) within the Red Deer River study area.

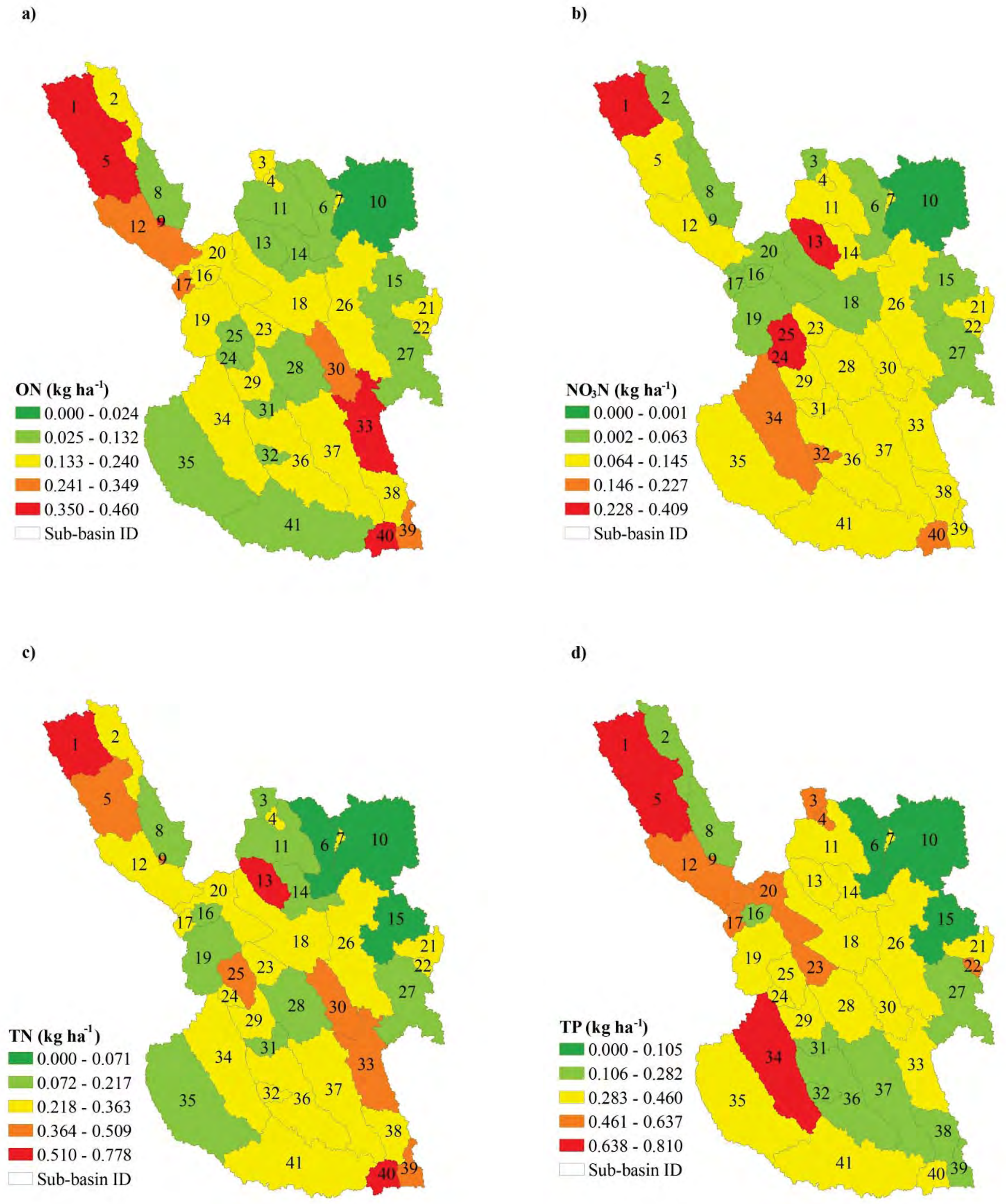

Figure 7.7. Sub-basin scale maps of export coefficients of (a) ON (organic nitrogen), (b) NO_3-N (nitrate nitrogen), (c) TN (total nitrogen), and (d) TP (total phosphorus) within the Red Deer River study area.

Table 7.36. Statistics of critical source area (High and Very High risk categories) estimated for selected environmental indicators at the subarea scale.

Environmental indicators[z]	Estimated threshold	Proportion of RDR study area[y]	Proportion of total load[x]
		(%)	(%)
TSS	≥ 0.12 Mg ha^{-1}	8	82
ON	≥ 0.81 kg ha^{-1}	12	60
OP	≥ 0.12 kg ha^{-1}	11	55
NO_3-N	≥ 0.23 kg ha^{-1}	22	61
PO_4-P	≥ 0.74 kg ha^{-1}	36	77
TN	≥ 0.97 kg ha^{-1}	12	49
TP	≥ 0.82 kg ha^{-1}	37	74
Average		20	65

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, and TP = total phosphorus.

[y] Ratio of critical source area relative to the total RDR study area.

[x] Ratio of critical source area load relative to RDR study area total load.

It is important to note that the CSA analyses are subject to the selected method of calculating risk categories and spatial scales. Selection of a different method of classification based on different threshold values and a different resolution of polygon scale would naturally result in different distributions of the CSAs. In other studies, White et al. (2009) estimated, using SWAT at HRU scale, that 5% of the watershed area produced 50% of the TSS and 34% of the TP loads, and Winchell et al. (2011) reported that 10% of the land area generated 74% of the TP load. In our study, comparable results were obtained for several of the environmental indicators used in the CSA analysis (Table 7.36).

7.4.13 Comparison of Net Economic Returns in Phase 1 and Phase 2 of the BMP Project

When comparing the BMP Project Phase 2 (RDR) results with the Phase 1 (IFC, WHC, and LLB; Jedrych et al. 2014) results, it is important to recognize some differences between the two studies. First, the BMPs evaluated in the RDR study were not the exact same as those in the Phase 1 study. Even in cases where the BMPs had similar or identical names, the specifications were different. Second, these two studies were conducted at different land scales. The RDR study area was 1,217,530 ha in size, while the Indianfarm Creek Watershed (IFC) was 14,145 ha, the Whelp Creek Sub-watershed (WHC) was 4595 ha, and the Lower Little Bow River Field (LLB) was 83 ha in size.

Since the study areas in Phase 1 were much smaller, it was possible to collect detailed farm-scale land management data through farm surveys. Consequently, a limited number of model representative farms were developed based on detailed information from specific study area farms. In the RDR study, the management data were based on the Census database assembled for the PFRA watershed-scale polygons. As a result, the management data in Phase 2 were generalized from a larger database and compiled into a much larger number of representative farms than in Phase 1.

Another major factor is that the animal unit density was more than two times higher in the Phase 1 study areas than in the RDR study area. The IFC Watershed had several cattle backgrounding and finishing operations, while the WHC Sub-basin had several large dairy operations and a large hog operation. These large operations tend to incur higher manure management costs, particularly associated with manure hauling costs (Osei and Keplinger 2008).

The economic results for Phases 1 and 2 of the Nutrient BMP Evaluation Project are presented in Table 7.37, which shows the estimated net economic returns resulting from the implementation of the modeled BMPs. The results for the RDR study displayed a similar pattern to the Phase 1 (IFC, WHC, and LLB) results despite project differences. In general, the farm economic model estimated a negative return for the majority of farm operations that implemented the proposed BMPs.

The Manure Agronomic P Management BMP had the highest negative returns ranging from \$15.50 to \$67.50 ha^{-1} yr^{-1} in the IFC, WHC, and LLB watersheds. However, for the RDR study, the same BMP generated a positive return of \$0.42 ha^{-1} yr^{-1}. As explained above, the primary reason for this difference is that the farm sizes and animal unit densities were generally smaller in the RDR study area and that manure handling costs were considerably lower. As well, smaller farms in the RDR study area were better able to realize fertilizer cost savings, which offset the increased manure application costs. The more intensive livestock operations in other watersheds generally incurred higher manure hauling and application costs, which were higher than fertilizer cost savings.

The Rotational Grazing and Controlled Access BMP in the RDR study also had a positive economic return of \$3.94 ha^{-1} yr^{-1}. In contrast, the Riparian Setbacks and Grassed Waterways BMPs resulted in negative economic returns of \$4.72 and \$2.82 ha^{-1} yr^{-1}, respectively. If all three of these BMPs were implemented, then the overall net return would be negative, and in the range of \$3.60 ha^{-1} yr^{-1}. This is comparable to the results for the composite BMPs modelled in the Phase 1 study for the IFC Watershed, which resulted in a negative return of \$1.31 ha^{-1} yr^{-1}. Comparison of the remaining BMPs of these two studies showed that the net returns were also negative and were in the same order of magnitude ranging from \$0.44 to \$3.77 ha^{-1} yr^{-1}.

Table 7.37. Comparison of FEM estimated net returns for different beneficial management practices (BMPs) from the Phase 1 and 2 studies.[z]

	Net return (\$ ha^{-1} yr^{-1})			
	Phase 1 study[y,x]			Phase 2 study
CEEOT simulated BMPs	IFC	WHC	LLB	RDR
Manure agronomic P management	-15.80	-67.5	-36.04[w]	0.42
Rotational grazing and controlled access	-1.31[w]	na[v]	Na	3.94
Riparian setbacks	-1.31[w]	-1.68[w]	Na	-4.72
Grassed waterways	-1.31[w]	-1.68[w]	-36.04[w]	-2.82
Wetland restoration	na	-1.68[w]	na	-3.77
Seasonal bedding and feeding	na	na	na	-0.44
Reduced tillage in fall	na	-1.68[w]	na	na
Irrigation efficiency	na	na	-3.58	na

[z] RDR = Red Deer River, IFC = Indianfarm Creek Watershed, WHC = Whelp Creek Sub -watershed, LLB = Lower Little Bow River Field.

[y] Jedrych et al. (2014).

[x] Net return values of selected BMPs were normalized against the Alberta Agricultural Operation Practices management practices scenario.

[w] Cumulative BMPs had the same net return values.

[v] na = not applicable.

8 CONCLUSIONS AND RECOMMENDATONS

8.1 Conclusions and Key Findings

Six BMP scenarios were evaluated throughout a portion (RDR study area) of the RDR Watershed. The scenarios represented a range of farm management practices that have the potential to improve environmental indicators for streams and other water bodies. Unlike the CEEOT applications for the Indianfarm Creek and Whelp Creek watersheds and the Lower Little Bow field site in Phase 1, no scenarios were restricted to selected field sites. Most of the scenarios evaluated for the RDR study area were structural practices, including wetlands, grassed waterways, riparian forest buffer, and seasonal bedding relocation. The remaining scenarios were manure P management and rotational grazing. While the findings obtained from this study were directly pertinent to the RDR study area, the implications are applicable to watersheds of similar nature, i.e., watersheds with similar land-use distribution and biophysical properties. The following are key findings from the CEEOT application to the RDR study area. In addition to these results, a variety of effects can be derived for any combinations of the six BMP scenarios.

For most of the BMP scenarios, there was a cost associated with the environmental improvements.

- Manure management to supply but not exceed crop P requirements (Scenario 2) will result in reduced losses of P to downstream waters bodies as compared to a baseline of over application of manure P. However, the impacts of manure P management relative to the baseline varied from one sub-basin to another depending on the baseline manure application rates and management as compared to Scenario 2. At the study area outlet, TN and TP were reduced, while runoff depth and TSS increased marginally. However, these environmental indicators varied considerably among the sub-basins. Scenario 2 was the only scenario that resulted in an increase in the amount of manure hauled off-farm, including farms that were hauling manure in the baseline scenario as well as those that were not.
- Scenario 2 economic simulations also indicate that the manure P management scenario could result in a profit loss or gain depending primarily on land availability and how manure is currently handled relative to crop P requirements. But in general, the scenario results suggest slight improvement (\$0.42 ha^{-1} yr^{-1}) in farm profits in the RDR study area.
- Rotational grazing (Scenario 3) was shown to be most beneficial in terms of improving water quality indicators and increasing farm profits. Better management of livestock on pastures improved forage production, which consequently reduced runoff potential and TSS and nutrient export. In addition, there was a reduction in feed costs and an increase in farm revenue. On average, the increase was about \$4 ha^{-1} yr^{-1}. At the study area level, this amounted to more than \$3 million yr^{-1} in additional farm profits.

- For Scenarios 4, 5, 6, and 7, there were costs associated with the environmental improvements. The cost was minimal (\$0.44 ha^{-1} yr^{-1}) for Scenario 4 (seasonal bedding and feeding sites); however, the environmental improvements were modest. Scenarios 5 (grassed waterways) and 7 (wetland restoration) resulted in small improvements to most of the environmental indicators at modest costs (\$2.82 and \$3.77 ha^{-1} yr^{-1}, respectively). Scenario 6 (riparian setbacks) generally demonstrated the largest environmental improvements but the costs were also the highest (4.72 ha^{-1} yr^{-1}). When it was implemented throughout the study area where applicable, the overall costs to the region amounted to almost \$4 million yr^{-1}.

Combing BMPs could improve economic impacts.

- This project focused on six independently assessed BMP scenarios. While some of the BMPs contained more than one farm management feature, those features were generally limited to that specific project BMP. Improved results may be possible by creating additional scenarios that combine BMPs, such as combining rotational grazing with one of the structural practices.

Cost-effectiveness estimates indicated that not all scenarios had similar effects on all environmental indicators. For each environmental indicator, specific scenarios or scenario combinations can be recommended as the most cost-effective.

- Cost-effectiveness values presented for all scenarios and indicators in each sub-basin showed that some scenarios will achieve the reductions for a given indicator much more cost-effectively than others. In particular, Scenario 4 was quite cost-effective for many of the indicators, but may not achieve the reduction goal desired if used alone. Furthermore, Scenario 3 is indicated to be a win-win scenario since a profit increase was projected.
- Differing cost-effectiveness values often indicate that on a watershed scale, environmental indicator reduction goals can be achieved if more flexible and well-targeted options are used rather than a blanket implementation approach.

-
- **Economic and water quality impacts of manure management depend to a large extent on the size distribution of farms in the area of interest. The comparison of Phase 1 (IFC, WHC, LLB) and Phase 2 (RDR) results implied that the distribution of farm sizes and available land areas is the primary driver behind the economics of manure handling in Alberta.**
-
    - For regions that have smaller livestock operations and relatively lower animal densities, manure management may result in an overall cost-savings to the livestock operations. That is because these farms are more likely able to apply the manure on-farm, resulting in fertilizer cost savings that more than offset the increased cost of manure nutrient applications.
    - On the other hand, for regions that have larger livestock operations with higher animal unit densities, improved manure nutrient management BMPs would result in higher costs, primarily because of additional hauling and manure spreading costs, which more than offset any fertilizer cost savings.
    - Regardless of the distribution of farm sizes, improved manure nutrient management will generally result in lower phosphorus losses, and may also lead to reduced nitrogen losses.

Targeting critical source areas for BMP implementation may increase the chance of positive effects on water quality.

- Critical source area analysis at the sub-basin scale showed that some sub-basins have higher potential for generating greater amount of flow, sediment, and nutrients. Sub-basin 1 produced the largest amount of flow, sediment, and nutrients among all RDR sub-basins.
- The subarea-scale critical source area varied among the environmental indicators (TSS, ON, OP, NO_3-N, PO_4-P, TN, and TP). It was estimated that 12% and 37% of the total RDR study area exported 49% and 74% of TN and TP loads, respectively. Averaged among the seven environmental indicators, the critical source area was 20% of the total RDR study area; whereas, and the critical source area contributed 65% to the total load of the environmental indicators.

8.2 Lessons Learned and Suggestions for Model Improvement

Phase 1 of the modelling component of the Nutrient BMP Evaluation Project examined the performance of the CEEOT using field data from the Indianfarm Creek and Whelp Creek watersheds and the Lower Little Bow field site (Jedrych et al. 2014). In Phase 1, considerable time and effort were dedicated to adapt the modelling system to the Alberta environment by automating the data entry process, calibrating and evaluating model performance under Alberta conditions, and developing new BMP scenario simulations for Alberta farms. The experiences and lessons learned from Phase 1 were applied to the RDR study and greatly improved the project development and timelines. Through the application of the CEEOT model to the RDR study area, a number of additional lessons were learned that will improve application of the model to other provincial watersheds in the future.

8.2.1 Data Availability

Data are readily available. The vast majority of data needed to conduct watershed assessments have been identified and are readily available. Key biophysical data such as soils, land use, and DEM data are likely available in sufficient detail for each watershed in the province. Previous experience has shown that more refined details are not necessary to arrive at reasonably accurate conclusions for future watershed analyses. Similarly, most of the economic data required for farm-scale or regional economic assessments are also available. Farm size and livestock inventory data can also be gleaned from Census aggregates and used to generate representative farms using the methods described in Osei et al. (2003) and employed in the current study. The key data that need to be verified for each locale are farm management practices and water monitoring data.

Data entry must be automated as much as possible. To avoid or at least minimize the time lost due to human error or the sheer time needed to perform manual data entry and manipulations, a data entry routine and programmable data entry forms need to be developed and used for future watershed applications. Previous CEEOT applications have used some survey instruments and Excel Visual Basic for Applications (VBA) scripts for data manipulation procedures that can be adapted for Alberta.

8.2.2 SWAPP Model Calibration

During the calibration process, it was discovered that one set of APEX parameters (Table 5.3) was not sufficient to obtain good SWAPP calibration results for large and hydrologically diversified areas such as the RDR study area. Based on this observation, it is recommended that future versions of the SWAPP model need to be modified to allow the option of providing different parameter values in the PARM0604.dat file used for APEX calibration of individual sub-basins.

The SWAPP prediction accuracy was affected by lack of input data relating to subarea-routing sequence and the generalized subarea configuration used in the calibration. This was related to the scale of the modelling area, and the configuration of a large number of HRUs defined for each sub-basin. Consequently, it was assumed that HRU areas were equivalent in size to the APEX model subareas. Based on this assumption, the models calculated results for each subarea separately and then added them to estimate environmental effects from each sub-basin. This assumption also limited estimation of the effect of spatial interaction among subareas in individual sub-basins. In future projects, it is recommended that large watersheds such as the RDR study area be configured into a larger number of sub-basins with fewer HRUs in order to better simulate the effects of interaction between adjacent subareas.

8.2.3 BMP and Scenario Simulation

Future BMP scenario simulations can be conducted relatively quickly using CEEOT if the scenarios are similar to those developed in completed Alberta BMP projects. A number of new scenario features were programmed during the current application (including dynamic manure transfers between sub-basins), in addition to the new features that were developed in the previous Alberta CEEOT application (Jedrych et al. 2014). However, if additional scenarios are conceived that require new programming features, additional time will be required in future studies to develop the programs and to augment them into the CEEOT model.

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10 APPENDICES

Appendix 1. List of Census farm attribute variables.

Table A1. List of Census farm attribute variables used to develop the Red Deer River study area representative farms.

Census label	Census farm attribute variable
TFAREA	Total area of farms - hectares
TCATTL	Total cattle and calves - number
TOTWHT	Total, wheat - hectares
OATS	Oats - hectares
BARLEY	Barley - hectares
CANOLA	Canola (rapeseed) - hectares
TFORAGE	Total, forage land - hectares
DFPEAS	Dry field peas - hectares
ALFALFA	Alfalfa and alfalfa mixtures - hectares
OTTAME	All other tame hay and fodder crops - hectares
IMPAST	Tame or seeded pasture - hectares
UNIMPST	Natural land for pasture - hectares
SUMMRF	Summer fallow - hectares
MLKCOW	Dairy cows - number
BFCOWS	Beef cows - number
CATTLE	Selected cattle - number
TOPIGS	Total pigs - number
TSHEEP	Total sheep and lambs - number
TCHICK	Total hens and chickens - number
TURKEY	Turkeys - Number

Appendix 2. Visual comparison between measured and SWAPP predicted environmental results for the five Alberta Environmentally Sustainable Agriculture Water Quality Program sub-basins in the Red Deer River study area.

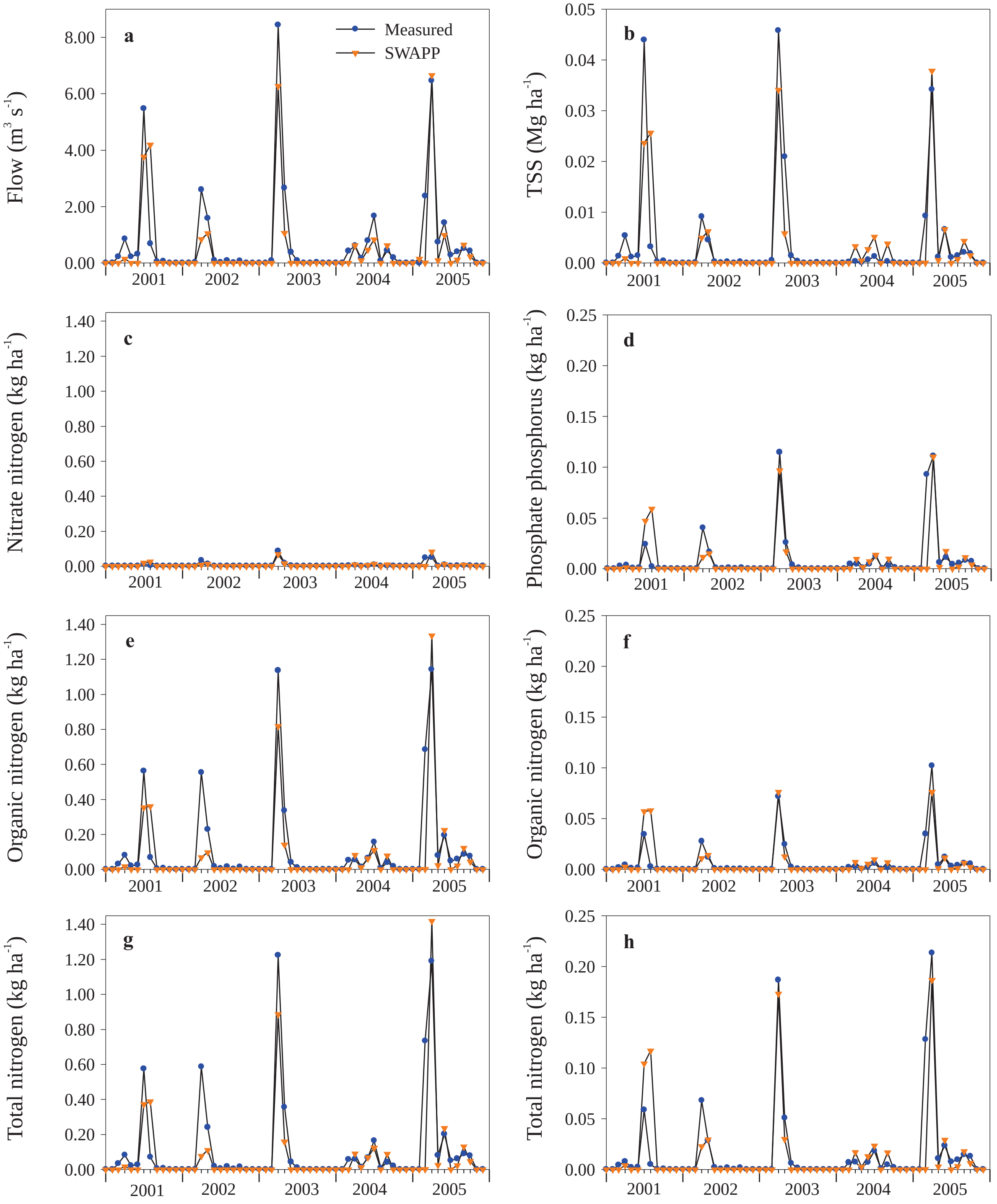

Figure A2.1. Measured and SWAPP-predicted average monthly values for (a) flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at the Blindman River outlet (Sub-basin 1) from 2001 to 2005.

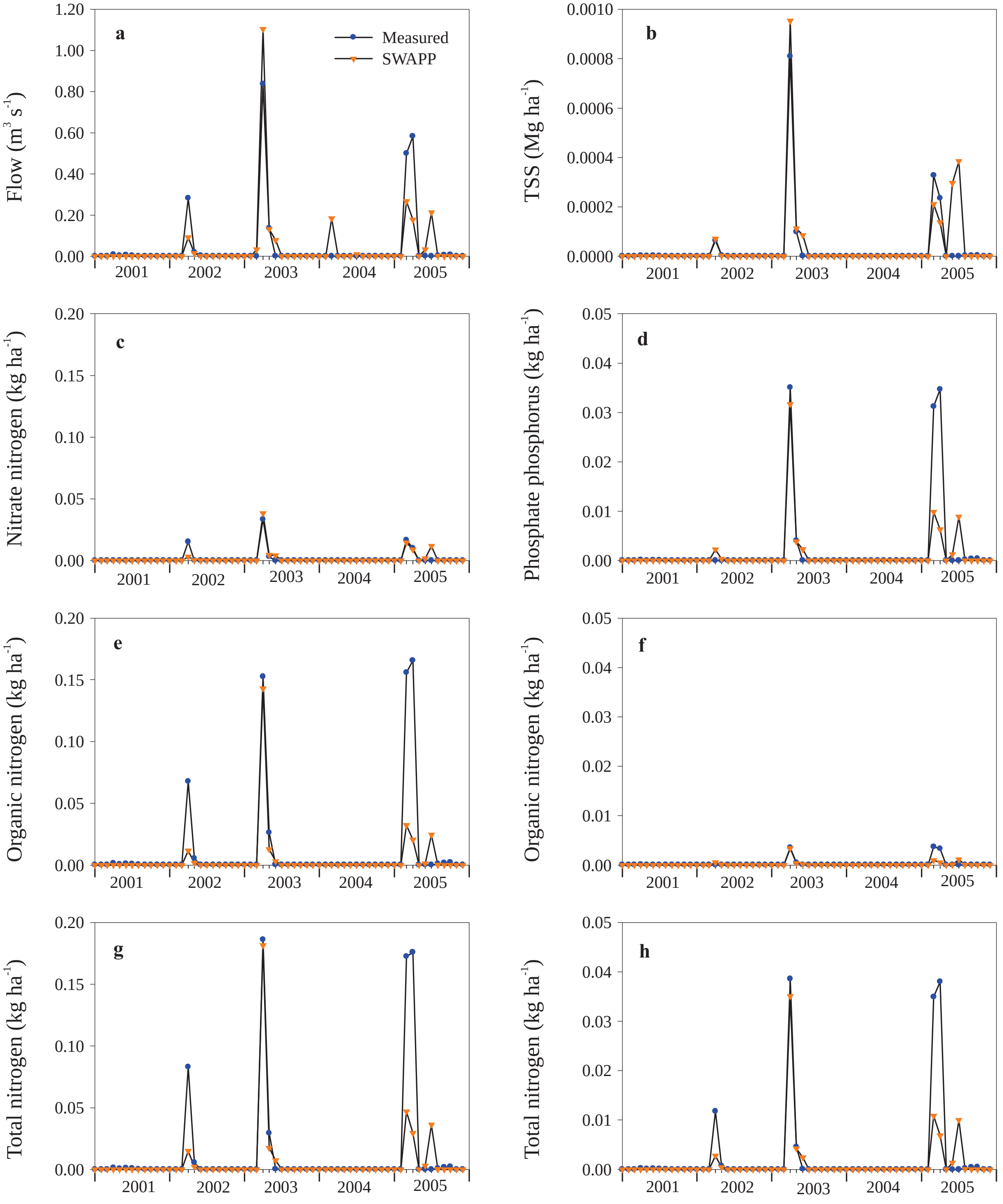

Figure A2.2. Measured and SWAPP-predicted average monthly values for (a) flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at the Haynes Creek

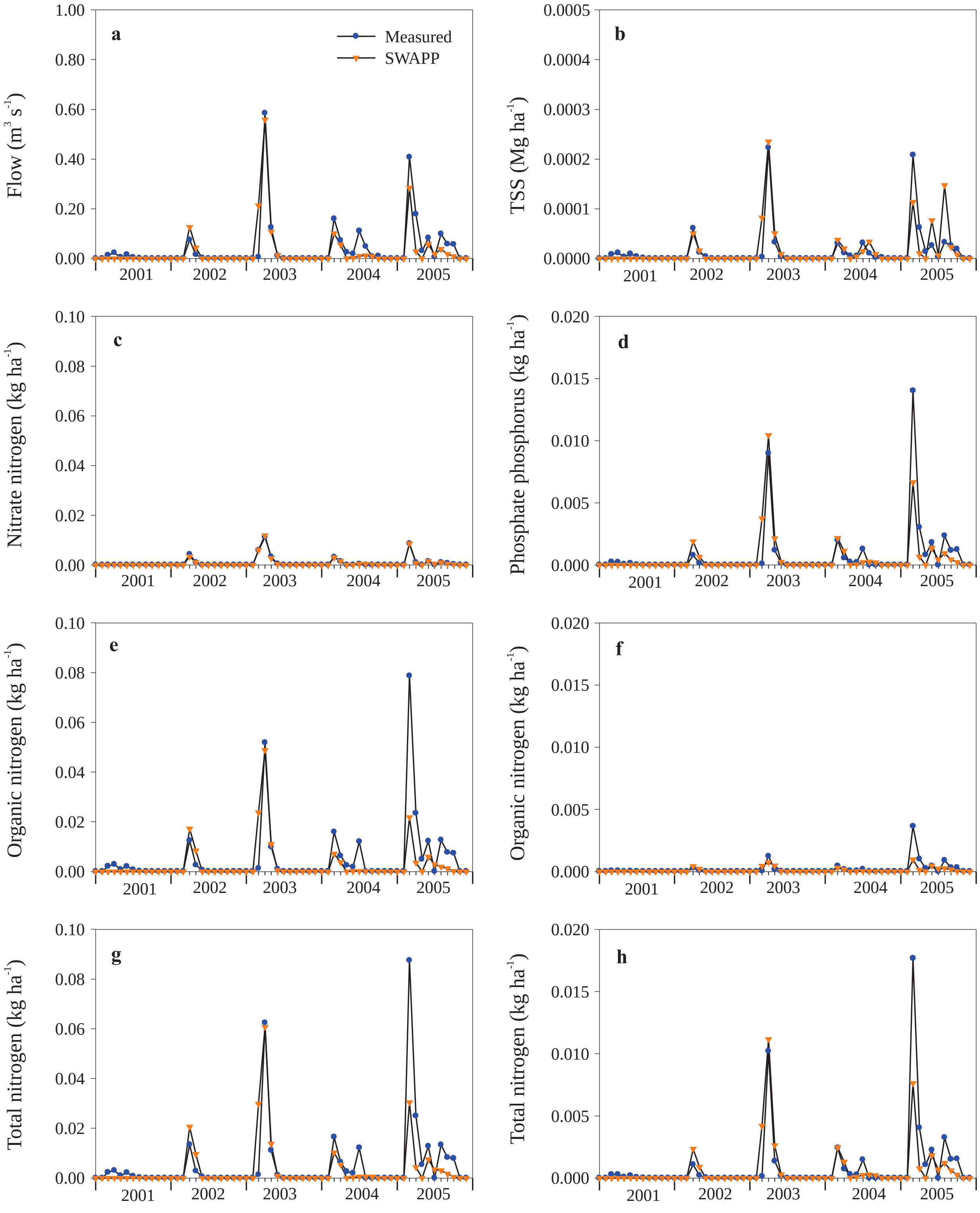

Figure A2.3. Measured and SWAPP-predicted average monthly values for (a) flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at the Ray Creek outlet (Sub-basin 24) from 2001 to 2005.

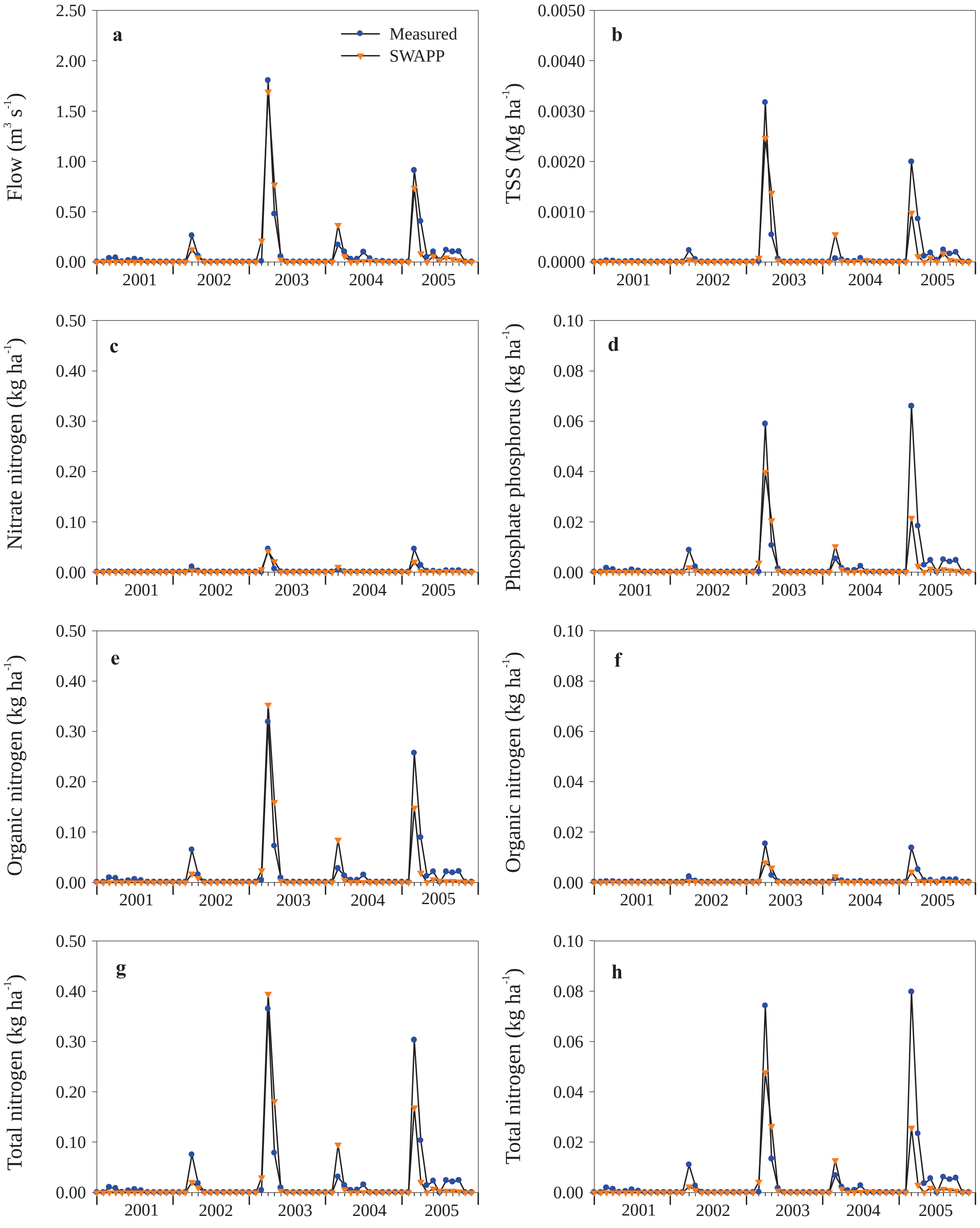

Figure A2.4. Measured and SWAPP-predicted average monthly values for (a) flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at the Threehills Creek outlet (Sub-basin 25) from 2001 to 2005.

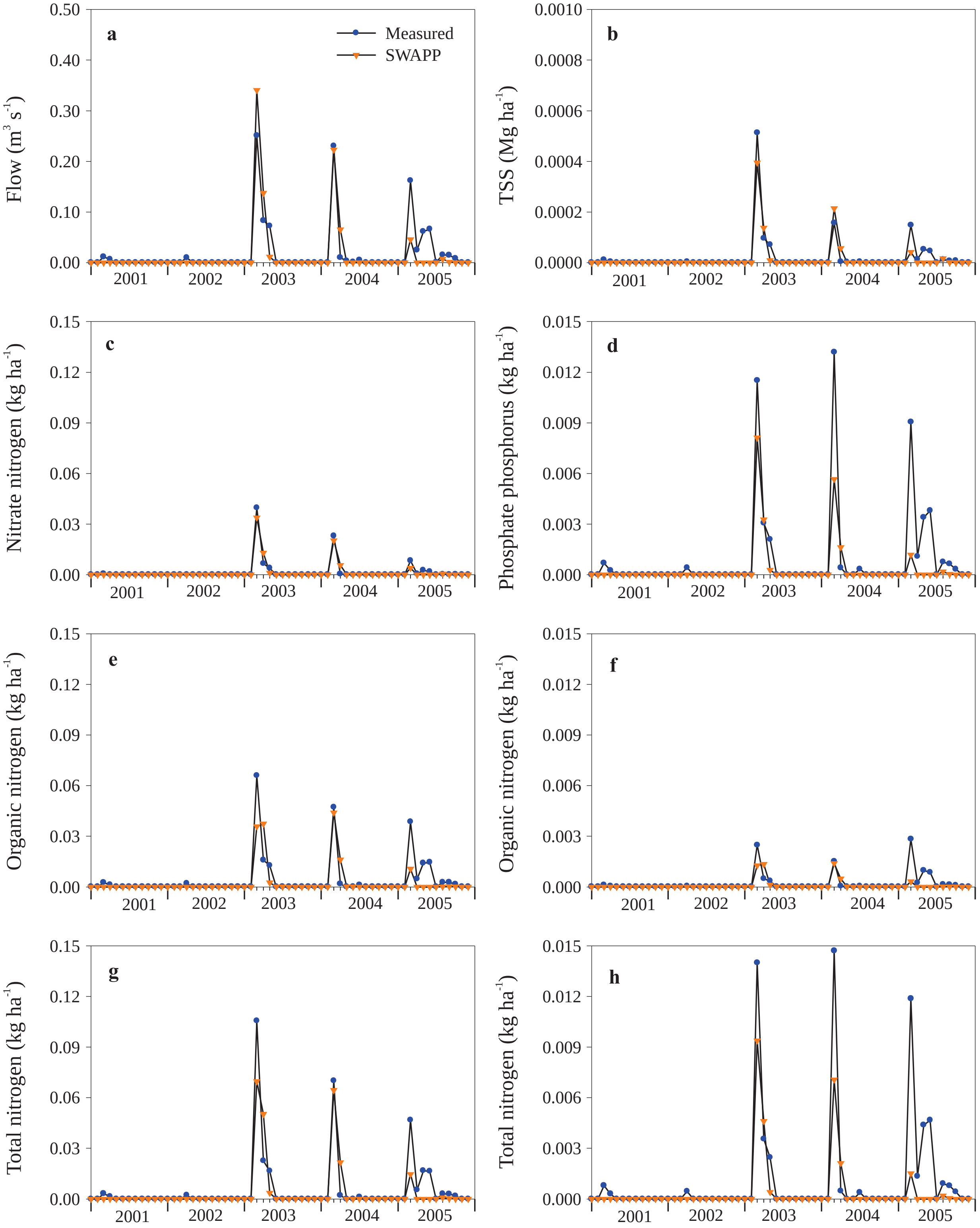

Figure A2.5. Measured and SWAPP-predicted average monthly values for (a) flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at the Renwick Creek outlet (Sub-basin 32) from 2001 to 2005.

Appendix 3. APEX and SWAPP estimated average annual runoff depth, total suspended solids, and nutrient values.

Table A 3.1a. APEX estimated annual average values at the edge-of-field (subarea) within the Red Deer River study area for Scenario 2 (Manure Phosphorus Management). The AESA sub-basins are shown in bold.

Sub-basin	Modelled area (ha)	Runoff depth (mm)	TSS and nutrient export coefficients[z]						
			TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
			(Mg ha^{-1})	------------------------ (kg ha^{-1}) ------------------------					
1	**35,394**	**62.4**	**0.057**	**0.57**	**0.09**	**0.26**	**0.43**	**0.83**	**0.52**
2	25,323	17.5	0.036	0.18	0.03	0.06	0.17	0.23	0.20
3	7,049	7.4	0.010	0.09	0.03	0.11	0.25	0.20	0.28
4	3,118	8.4	0.011	0.12	0.03	0.12	0.27	0.23	0.30
5	43,230	17.4	0.031	0.28	0.07	0.12	0.32	0.40	0.39
6	31,060	7.6	0.014	0.05	0.02	0.03	0.06	0.08	0.08
7	1,329	13.1	0.010	0.25	0.06	0.08	0.32	0.33	0.39
8	20,092	8.1	0.016	0.08	0.02	0.02	0.08	0.11	0.09
9	708	11.4	0.017	0.17	0.03	0.08	0.17	0.25	0.20
10	55,995	0.0	0.000	0.00	0.00	0.00	0.00	0.00	0.00
11	39,794	12.0	0.013	0.13	0.03	0.09	0.26	0.22	0.29
12	44,768	12.5	0.022	0.20	0.05	0.08	0.25	0.28	0.30
13	**17,445**	**20.6**	**0.003**	**0.16**	**0.03**	**0.21**	**0.28**	**0.37**	**0.31**
14	20,514	11.9	0.006	0.08	0.02	0.07	0.20	0.15	0.22
15	33,842	4.3	0.008	0.03	0.01	0.02	0.06	0.06	0.07
16	2,763	15.1	0.022	0.21	0.04	0.03	0.05	0.25	0.09
17	4,729	14.8	0.023	0.18	0.03	0.06	0.19	0.23	0.22
18	53,062	11.1	0.018	0.13	0.03	0.06	0.21	0.19	0.24
19	35,641	14.8	0.019	0.21	0.04	0.06	0.27	0.26	0.31
20	29,237	14.9	0.021	0.20	0.04	0.06	0.23	0.26	0.26
21	13,177	12.1	0.019	0.12	0.04	0.09	0.18	0.21	0.22
22	2,673	11.7	0.013	0.07	0.03	0.10	0.22	0.17	0.25
23	13,496	12.3	0.012	0.12	0.03	0.10	0.29	0.23	0.33
24	**4,523**	**29.3**	**0.003**	**0.12**	**0.01**	**0.16**	**0.39**	**0.28**	**0.40**
25	**15,379**	**27.6**	**0.008**	**0.10**	**0.02**	**0.20**	**0.23**	**0.30**	**0.24**
26	66,468	12.9	0.024	0.14	0.04	0.06	0.15	0.20	0.19
27	45,708	7.8	0.017	0.05	0.03	0.03	0.06	0.08	0.09
28	38,123	13.1	0.027	0.18	0.04	0.05	0.17	0.23	0.21
29	17,446	16.5	0.026	0.27	0.05	0.08	0.23	0.35	0.28
30	25,153	14.2	0.027	0.17	0.04	0.09	0.21	0.26	0.26
31	9,073	9.5	0.009	0.12	0.01	0.04	0.21	0.16	0.22
32	**5,796**	**20.3**	**0.003**	**0.05**	**0.01**	**0.10**	**0.22**	**0.15**	**0.22**
33	38,032	21.0	0.025	0.23	0.05	0.11	0.16	0.34	0.21
34	65,215	27.2	0.028	0.37	0.06	0.11	0.45	0.48	0.51
35	87,268	18.6	0.016	0.14	0.02	0.07	0.25	0.21	0.27
36	55,237	19.2	0.022	0.19	0.03	0.06	0.22	0.25	0.24
37	60,650	22.4	0.039	0.19	0.04	0.04	0.07	0.24	0.11
38	19,016	20.3	0.022	0.16	0.02	0.05	0.09	0.22	0.11
39	9,144	21.8	0.024	0.17	0.03	0.06	0.12	0.23	0.14
40	9,817	17.5	0.016	0.12	0.06	0.16	0.15	0.28	0.21
41	81,397	17.6	0.014	0.24	0.02	0.12	0.29	0.36	0.31

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

Table A3.1b. SWAPP estimated cumulative environmental results at the outlet of each sub-basin for Scenario 2 (Manure Phosphorus Management). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Runoff depth (mm)	TSS and nutrient export coefficients[z]						
	Individual	Cumulative			TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------				(Mg ha^{-1})	----------------- (kg ha^{-1}) -----------------					
17	4,729	1,164,729[y]		114.0	0.049	0.42	0.03	0.09	0.03	0.50	0.06
19	35,641	35,641	Tr.1	14.8	0.021	0.17	0.03	0.06	0.28	0.23	0.30
16	6,541	1,206,912		112.1	0.096	0.34	0.02	0.20	0.05	0.54	0.07
1	35,394	35,394	Tr.2.2.2	62.3	0.057	0.46	0.07	0.26	0.45	0.72	0.52
2	25,323	25,323	Tr.2.2.1	17.5	0.040	0.14	0.02	0.06	0.18	0.20	0.20
5	43,230	103,947	Tr.2.2	32.8	0.060	0.25	0.04	0.15	0.34	0.40	0.38
8	29,263	29,263	Tr.2.1.1	5.6	0.011	0.05	0.01	0.02	0.06	0.06	0.06
9	708	29,971	Tr.2.1	5.7	0.002	0.04	0.01	0.01	0.06	0.05	0.06
12	44,768	178,686	Tr.2	23.2	0.054	0.16	0.03	0.11	0.28	0.27	0.31
20	29,238	1,414,835		98.9	0.165	0.25	0.02	0.18	0.08	0.44	0.10
18	53,062	1,467,897		95.7	0.196	0.20	0.01	0.18	0.09	0.38	0.11
13	17,445	17,445	Tr.3	20.7	0.004	0.13	0.02	0.21	0.29	0.34	0.30
14	20,514	1,505,856		93.7	0.234	0.16	0.01	0.18	0.10	0.34	0.11
3	7,049	7,049	Tr.4.1.1.1.1.1	7.5	0.010	0.07	0.02	0.11	0.25	0.18	0.27
4	3,118	10,167	Tr.4.1.1.1.1	7.8	0.011	0.07	0.02	0.11	0.26	0.18	0.28
11	39,794	49,961	Tr.4.1.1.1	11.2	0.013	0.10	0.02	0.09	0.26	0.19	0.28
6	31,060	81,020	Tr.4.1.1	9.8	0.015	0.06	0.02	0.07	0.19	0.13	0.20
7	1,329	82,349	Tr.4.1	9.9	0.003	0.06	0.01	0.05	0.19	0.11	0.20
10	72,691	155,040	Tr.4	5.3	0.001	0.03	0.01	0.02	0.10	0.05	0.10
15	33,842	33,842	Tr.5	4.3	0.009	0.03	0.01	0.02	0.06	0.05	0.07
26	66,468	1,761,206		81.1	0.260	0.12	0.01	0.16	0.10	0.28	0.11
21	13,177	13,177	Tr.6.1.1	12.2	0.019	0.10	0.03	0.09	0.19	0.19	0.22
22	2,673	15,850	Tr.6.1	12.2	0.004	0.08	0.02	0.08	0.19	0.16	0.21
27	45,708	61,558	Tr.6	8.9	0.019	0.05	0.02	0.04	0.10	0.09	0.12
30	25,153	25,153	Tr.7	14.3	0.033	0.14	0.03	0.09	0.22	0.23	0.25
33	38,032	1,885,950		76.7	0.273	0.10	0.01	0.15	0.11	0.25	0.11
24	4,523	4,523	Tr.8.2.2.1.1.1.1	29.4	0.003	0.10	0.01	0.16	0.39	0.26	0.40
25	15,379	19,902	Tr.8.2.2.1.1	28.0	0.007	0.08	0.01	0.19	0.27	0.28	0.28
29	17,446	37,348	Tr.8.2.2.1	22.7	0.020	0.14	0.02	0.14	0.26	0.28	0.28
31	9,073	46,422	Tr.8.2.2	20.1	0.006	0.12	0.02	0.10	0.25	0.22	0.26
32	5,796	5,796	Tr.8.2.1	20.2	0.003	0.04	0.00	0.10	0.22	0.14	0.22
36	55,237	107,454	Tr.8.2	19.7	0.030	0.12	0.01	0.08	0.23	0.20	0.25
23	13,496	13,496	Tr.8.1.1	12.4	0.012	0.10	0.03	0.10	0.30	0.21	0.33
28	38,123	51,619	Tr.8.1	13.0	0.026	0.13	0.03	0.06	0.21	0.19	0.24
37	60,650	219,724	Tr.8	18.8	0.043	0.12	0.02	0.07	0.19	0.19	0.21
38	19,016	2,124,690		72.5	0.269	0.10	0.01	0.15	0.16	0.25	0.16
34	65,215	65,215	Tr.9.1.2	27.2	0.037	0.31	0.04	0.11	0.46	0.42	0.50
35	87,268	87,268	Tr.9.1.1	18.6	0.018	0.11	0.02	0.07	0.26	0.18	0.27
41	81,397	233,880	Tr.9.1	20.7	0.041	0.17	0.02	0.10	0.33	0.27	0.35
40	9,817	243,698	Tr.9	20.5	0.045	0.14	0.01	0.10	0.33	0.24	0.34
39	**9,144**	**2,377,531**		**64.9**	**0.249**	**0.07**	**0.00**	**0.14**	**0.14**	**0.21**	**0.15**

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Table A3 .2a. APEX estimated annual average values at the edge-of-field (subarea) within the Red Deer River study area for Scenario 3 (Rotational Grazing). The AESA sub -basins are shown in bold.

Sub-basin	Modelled area (ha)	Runoff depth (mm)	TSS and nutrient export coefficients^z						
			TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
			(Mg ha^{-1})	---------------------------- (kg ha^{-1}) -----------------------------					
1	**35,394**	**56.4**	**0.052**	**0.41**	**0.08**	**0.28**	**0.62**	**0.69**	**0.70**
2	25,323	15.9	0.033	0.15	0.03	0.05	0.20	0.20	0.23
3	7,049	6.2	0.005	0.09	0.03	0.06	0.34	0.14	0.37
4	3,118	7.3	0.009	0.16	0.03	0.06	0.40	0.22	0.43
5	43,230	15.9	0.028	0.30	0.06	0.09	0.52	0.40	0.59
6	31,060	5.6	0.011	0.03	0.01	0.01	0.05	0.04	0.06
7	1,329	11.6	0.010	0.17	0.06	0.06	0.32	0.23	0.38
8	20,092	7.4	0.015	0.08	0.02	0.02	0.09	0.10	0.11
9	708	11.0	0.004	0.34	0.04	0.05	0.44	0.39	0.48
10	55,995	0.0	0.000	0.00	0.00	0.00	0.00	0.00	0.00
11	39,794	10.2	0.012	0.08	0.02	0.06	0.29	0.14	0.31
12	44,768	11.1	0.018	0.21	0.04	0.06	0.37	0.28	0.41
13	**17,445**	**17.0**	**0.003**	**0.10**	**0.02**	**0.29**	**0.27**	**0.39**	**0.29**
14	20,514	10.3	0.005	0.09	0.02	0.06	0.30	0.15	0.32
15	33,842	2.2	0.004	0.02	0.01	0.01	0.04	0.03	0.05
16	2,763	15.2	0.010	0.18	0.04	0.03	0.20	0.21	0.24
17	4,729	13.9	0.015	0.25	0.04	0.05	0.45	0.30	0.50
18	53,062	9.2	0.016	0.12	0.03	0.05	0.23	0.17	0.26
19	35,641	13.5	0.017	0.15	0.03	0.05	0.34	0.20	0.38
20	29,237	13.7	0.016	0.19	0.03	0.05	0.36	0.24	0.40
21	13,177	9.2	0.014	0.15	0.03	0.08	0.30	0.22	0.34
22	2,673	9.4	0.009	0.18	0.04	0.11	0.39	0.29	0.43
23	13,496	10.1	0.009	0.16	0.03	0.08	0.40	0.24	0.44
24	**4,523**	**29.8**	**0.007**	**0.08**	**0.01**	**0.26**	**0.34**	**0.34**	**0.35**
25	**15,379**	**25.4**	**0.007**	**0.10**	**0.01**	**0.22**	**0.37**	**0.31**	**0.38**
26	66,468	11.3	0.020	0.16	0.04	0.07	0.24	0.22	0.28
27	45,708	5.8	0.013	0.07	0.02	0.03	0.07	0.09	0.09
28	38,123	11.1	0.024	0.12	0.03	0.05	0.20	0.17	0.23
29	17,446	15.1	0.027	0.20	0.04	0.11	0.25	0.31	0.29
30	25,153	10.9	0.020	0.18	0.04	0.09	0.29	0.27	0.33
31	9,073	9.0	0.013	0.10	0.02	0.08	0.24	0.18	0.25
32	**5,796**	**19.2**	**0.004**	**0.03**	**0.01**	**0.19**	**0.15**	**0.22**	**0.16**
33	38,032	20.1	0.024	0.33	0.06	0.14	0.29	0.46	0.35
34	65,215	24.6	0.029	0.17	0.04	0.13	0.56	0.30	0.61
35	87,268	17.4	0.018	0.08	0.02	0.08	0.31	0.17	0.33
36	55,237	18.5	0.026	0.16	0.03	0.11	0.19	0.27	0.22
37	60,650	22.3	0.035	0.21	0.05	0.08	0.10	0.28	0.15
38	19,016	20.4	0.021	0.20	0.03	0.07	0.14	0.27	0.17
39	9,144	21.7	0.023	0.31	0.04	0.11	0.23	0.42	0.27
40	9,817	17.0	0.013	0.40	0.07	0.15	0.31	0.55	0.38
41	81,397	16.7	0.015	0.11	0.02	0.13	0.38	0.24	0.40

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

Table 3.2b. SWAPP estimated cumulative environmental results at the outlet of each sub-basin for Scenario 3 (Rotational Grazing). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Runoff depth	TSS and nutrient export coefficients[z]						
	Individual	Cumulative		depth	TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			(mm)	(Mg ha^{-1})	----------------- (kg ha^{-1}) --------------------					
17	4,729	1,164,729[y]		114.0	0.049	0.42	0.03	0.09	0.03	0.50	0.06
19	35,641	35,641	Tr.1	13.5	0.018	0.12	0.02	0.05	0.35	0.17	0.37
16	6,541	1,206,912		112.1	0.096	0.34	0.02	0.20	0.05	0.54	0.07
1	35,394	35,394	Tr.2.2.2	56.4	0.052	0.34	0.06	0.28	0.64	0.62	0.70
2	25,323	25,323	Tr.2.2.1	15.9	0.037	0.12	0.02	0.05	0.20	0.17	0.22
5	43,230	103,947	Tr.2.2	29.7	0.054	0.22	0.04	0.14	0.50	0.36	0.53
8	29,263	29,263	Tr.2.1.1	5.1	0.010	0.04	0.01	0.01	0.06	0.06	0.07
9	708	29,971	Tr.2.1	5.3	0.002	0.04	0.01	0.01	0.07	0.05	0.08
12	44,768	178,686	Tr.2	21.0	0.048	0.15	0.02	0.10	0.40	0.25	0.43
20	29,238	1,414,835		98.5	0.163	0.25	0.02	0.18	0.11	0.44	0.12
18	53,062	1,467,897		95.3	0.194	0.20	0.01	0.18	0.11	0.38	0.13
13	17,445	17,445	Tr.3	17.1	0.004	0.08	0.01	0.29	0.27	0.37	0.29
14	20,514	1,505,856		93.2	0.232	0.16	0.01	0.18	0.12	0.34	0.13
3	7,049	7,049	Tr.4.1.1.1.1.1	6.2	0.005	0.07	0.02	0.06	0.35	0.13	0.36
4	3,118	10,167	Tr.4.1.1.1.1	6.6	0.007	0.08	0.02	0.06	0.36	0.14	0.38
11	39,794	49,961	Tr.4.1.1.1	9.5	0.012	0.07	0.02	0.05	0.30	0.12	0.32
6	31,060	81,020	Tr.4.1.1	8.0	0.012	0.04	0.01	0.04	0.21	0.08	0.22
7	1,329	82,349	Tr.4.1	8.1	0.002	0.04	0.01	0.02	0.20	0.07	0.21
10	72,691	155,040	Tr.4	4.3	0.001	0.02	0.00	0.01	0.11	0.03	0.11
15	33,842	33,842	Tr.5	2.2	0.005	0.01	0.00	0.01	0.04	0.03	0.05
26	66,468	1,761,206		80.6	0.257	0.12	0.01	0.15	0.13	0.27	0.13
21	13,177	13,177	Tr.6.1.1	9.3	0.014	0.12	0.03	0.08	0.31	0.20	0.34
22	2,673	15,850	Tr.6.1	9.3	0.003	0.11	0.02	0.06	0.32	0.17	0.34
27	45,708	61,558	Tr.6	6.7	0.014	0.06	0.02	0.04	0.14	0.10	0.16
30	25,153	25,153	Tr.7	11.0	0.024	0.15	0.03	0.09	0.30	0.23	0.33
33	38,032	1,885,950		76.0	0.270	0.10	0.01	0.15	0.13	0.25	0.14
24	4,523	4,523	Tr.8.2.2.1.1.1.1	29.9	0.007	0.07	0.01	0.26	0.34	0.32	0.35
25	15,379	19,902	Tr.8.2.2.1.1	26.5	0.007	0.07	0.01	0.23	0.36	0.30	0.37
29	17,446	37,348	Tr.8.2.2.1	21.2	0.020	0.11	0.02	0.17	0.31	0.28	0.33
31	9,073	46,422	Tr.8.2.2	18.8	0.006	0.10	0.01	0.13	0.30	0.22	0.31
32	5,796	5,796	Tr.8.2.1	19.2	0.004	0.02	0.00	0.19	0.15	0.21	0.16
36	55,237	107,454	Tr.8.2	18.7	0.031	0.10	0.02	0.12	0.24	0.22	0.26
23	13,496	13,496	Tr.8.1.1	10.2	0.010	0.13	0.03	0.08	0.41	0.22	0.43
28	38,123	51,619	Tr.8.1	10.9	0.023	0.10	0.02	0.05	0.26	0.15	0.28
37	60,650	219,724	Tr.8	17.8	0.041	0.11	0.02	0.09	0.21	0.20	0.23
38	19,016	2,124,690		71.7	0.265	0.09	0.01	0.16	0.19	0.25	0.20
34	65,215	65,215	Tr.9.1.2	24.7	0.036	0.14	0.03	0.13	0.57	0.27	0.60
35	87,268	87,268	Tr.9.1.1	17.4	0.020	0.07	0.02	0.08	0.31	0.15	0.33
41	81,397	233,880	Tr.9.1	19.2	0.039	0.08	0.02	0.11	0.41	0.20	0.43
40	9,817	243,698	Tr.9	19.1	0.044	0.08	0.01	0.12	0.41	0.20	0.43
39	**9,144**	**2,377,531**		**64.1**	**0.245**	**0.07**	**0.00**	**0.14**	**0.17**	**0.21**	**0.18**

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Table A3.3a. APEX estimated annual average values at the edge-of-field (subarea) within the Red Deer River study area for Scenario 4 (Seasonal Bedding). The AESA sub-basins are shown in bold.

Sub-basin	Modelled area (ha)	Runoff depth (mm)	TSS and nutrient export coefficients[z]						
			TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
			(Mg ha^{-1})	------------------------------ (kg ha^{-1}) ------------------------------					
1	**35,394**	**58.6**	**0.054**	**0.43**	**0.09**	**0.29**	**0.66**	**0.72**	**0.75**
2	25,323	16.2	0.033	0.16	0.03	0.05	0.22	0.21	0.24
3	7,049	7.2	0.005	0.14	0.03	0.05	0.42	0.19	0.45
4	3,118	8.2	0.010	0.20	0.04	0.06	0.47	0.26	0.50
5	43,230	16.9	0.029	0.37	0.07	0.09	0.59	0.45	0.66
6	31,060	6.7	0.013	0.03	0.02	0.02	0.06	0.06	0.08
7	1,329	12.0	0.009	0.22	0.07	0.06	0.34	0.28	0.40
8	20,092	7.8	0.016	0.09	0.02	0.02	0.10	0.11	0.12
9	708	10.9	0.004	0.02	0.00	0.05	0.48	0.06	0.48
10	55,995	0.0	0.000	0.00	0.00	0.00	0.00	0.00	0.00
11	39,794	11.3	0.012	0.10	0.03	0.07	0.33	0.17	0.36
12	44,768	11.3	0.018	0.24	0.04	0.06	0.41	0.30	0.45
13	**17,445**	**17.4**	**0.003**	**0.10**	**0.02**	**0.38**	**0.28**	**0.48**	**0.30**
14	20,514	10.9	0.005	0.12	0.02	0.06	0.34	0.18	0.36
15	33,842	3.2	0.006	0.03	0.01	0.01	0.06	0.05	0.07
16	2,763	15.2	0.010	0.18	0.04	0.03	0.20	0.21	0.24
17	4,729	13.8	0.015	0.29	0.05	0.04	0.49	0.34	0.54
18	53,062	10.3	0.017	0.16	0.03	0.05	0.27	0.21	0.30
19	35,641	12.8	0.015	0.15	0.03	0.05	0.34	0.19	0.37
20	29,237	14.1	0.016	0.22	0.04	0.05	0.39	0.27	0.43
21	13,177	10.8	0.016	0.19	0.04	0.08	0.36	0.28	0.41
22	2,673	10.2	0.008	0.23	0.04	0.10	0.42	0.33	0.46
23	13,496	11.3	0.009	0.20	0.04	0.09	0.45	0.29	0.50
24	**4,523**	**29.2**	**0.007**	**0.08**	**0.01**	**0.25**	**0.34**	**0.33**	**0.36**
25	**15,379**	**27.1**	**0.008**	**0.10**	**0.02**	**0.25**	**0.40**	**0.36**	**0.41**
26	66,468	11.6	0.020	0.17	0.04	0.06	0.25	0.24	0.29
27	45,708	6.1	0.014	0.08	0.03	0.03	0.08	0.11	0.10
28	38,123	11.1	0.023	0.11	0.03	0.06	0.21	0.17	0.24
29	17,446	15.3	0.027	0.20	0.04	0.13	0.26	0.33	0.30
30	25,153	12.4	0.021	0.24	0.05	0.10	0.34	0.33	0.39
31	9,073	8.7	0.012	0.09	0.02	0.08	0.23	0.17	0.25
32	**5,796**	**17.8**	**0.003**	**0.02**	**0.00**	**0.16**	**0.14**	**0.19**	**0.14**
33	38,032	19.6	0.022	0.35	0.06	0.12	0.29	0.48	0.35
34	65,215	23.8	0.027	0.17	0.04	0.12	0.55	0.29	0.60
35	87,268	17.6	0.018	0.08	0.02	0.08	0.33	0.16	0.35
36	55,237	18.2	0.026	0.15	0.03	0.10	0.20	0.26	0.22
37	60,650	22.3	0.035	0.21	0.05	0.08	0.10	0.28	0.15
38	19,016	20.4	0.021	0.20	0.03	0.07	0.14	0.27	0.17
39	9,144	21.5	0.023	0.31	0.04	0.11	0.23	0.42	0.27
40	9,817	16.7	0.012	0.44	0.08	0.13	0.30	0.57	0.38
41	81,397	16.0	0.013	0.10	0.02	0.12	0.38	0.22	0.40

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

Table A3.3b. SWAPP estimated cumulative environmental results at the outlet of each sub-basin for Scenario 4 (Seasonal Bedding). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area Individual (ha)	Modelled area Cumulative (ha)	Tributary (Tr) ID	Runoff depth (mm)	TSS and nutrient export coefficients[z] 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})
17	4,729	1,164,729[y]		114.0	0.049	0.42	0.03	0.09	0.03	0.50	0.06
19	35,641	35,641	Tr.1	12.8	0.016	0.12	0.02	0.05	0.34	0.17	0.37
16	6,541	1,206,912		112.0	0.096	0.34	0.02	0.20	0.05	0.54	0.07
1	35,394	35,394	Tr.2.2.2	58.6	0.054	0.35	0.06	0.29	0.68	0.64	0.75
2	25,323	25,323	Tr.2.2.1	16.2	0.037	0.13	0.02	0.05	0.22	0.18	0.24
5	43,230	103,947	Tr.2.2	30.9	0.056	0.25	0.04	0.14	0.54	0.39	0.58
8	29,263	29,263	Tr.2.1.1	5.4	0.011	0.05	0.01	0.01	0.07	0.06	0.08
9	708	29,971	Tr.2.1	5.5	0.002	0.04	0.01	0.01	0.08	0.05	0.08
12	44,768	178,686	Tr.2	21.8	0.050	0.17	0.03	0.10	0.44	0.27	0.46
20	29,238	1,414,835		98.6	0.164	0.26	0.02	0.18	0.11	0.44	0.13
18	53,062	1,467,897		95.4	0.195	0.20	0.01	0.18	0.12	0.38	0.13
13	17,445	17,445	Tr.3	17.5	0.004	0.08	0.01	0.38	0.29	0.46	0.30
14	20,514	1,505,856		93.4	0.232	0.16	0.01	0.18	0.13	0.34	0.14
3	7,049	7,049	Tr.4.1.1.1.1.1	7.2	0.005	0.11	0.02	0.05	0.42	0.16	0.45
4	3,118	10,167	Tr.4.1.1.1.1	7.5	0.007	0.12	0.02	0.05	0.44	0.17	0.46
11	39,794	49,961	Tr.4.1.1.1	10.6	0.012	0.08	0.02	0.06	0.35	0.14	0.37
6	31,060	81,020	Tr.4.1.1	9.1	0.014	0.05	0.01	0.05	0.24	0.10	0.25
7	1,329	82,349	Tr.4.1	9.2	0.003	0.05	0.01	0.03	0.24	0.08	0.25
10	72,691	155,040	Tr.4	4.9	0.001	0.03	0.00	0.01	0.12	0.03	0.13
15	33,842	33,842	Tr.5	3.2	0.007	0.03	0.01	0.01	0.06	0.04	0.07
26	66,468	1,761,206		80.8	0.258	0.12	0.01	0.16	0.13	0.28	0.14
21	13,177	13,177	Tr.6.1.1	10.9	0.016	0.16	0.03	0.08	0.37	0.24	0.40
22	2,673	15,850	Tr.6.1	10.8	0.003	0.15	0.03	0.06	0.37	0.21	0.40
27	45,708	61,558	Tr.6	7.3	0.015	0.08	0.02	0.04	0.16	0.12	0.18
30	25,153	25,153	Tr.7	12.5	0.026	0.20	0.04	0.10	0.35	0.29	0.39
33	38,032	1,885,950		76.2	0.271	0.10	0.01	0.15	0.14	0.25	0.15
24	4,523	4,523	Tr.8.2.2.1.1.1.1	29.3	0.007	0.07	0.01	0.25	0.35	0.31	0.36
25	15,379	19,902	Tr.8.2.2.1.1	27.7	0.008	0.08	0.01	0.25	0.39	0.33	0.40
29	17,446	37,348	Tr.8.2.2.1	21.9	0.020	0.11	0.02	0.19	0.33	0.31	0.35
31	9,073	46,422	Tr.8.2.2	19.4	0.006	0.10	0.01	0.15	0.31	0.24	0.33
32	5,796	5,796	Tr.8.2.1	17.8	0.003	0.02	0.00	0.16	0.14	0.19	0.14
36	55,237	107,454	Tr.8.2	18.7	0.031	0.10	0.02	0.12	0.25	0.22	0.26
23	13,496	13,496	Tr.8.1.1	11.4	0.010	0.17	0.03	0.09	0.46	0.25	0.50
28	38,123	51,619	Tr.8.1	11.2	0.022	0.11	0.02	0.06	0.28	0.16	0.30
37	60,650	219,724	Tr.8	17.9	0.041	0.11	0.02	0.09	0.22	0.20	0.24
38	19,016	2,124,690		71.8	0.266	0.09	0.01	0.16	0.20	0.25	0.21
34	65,215	65,215	Tr.9.1.2	23.8	0.035	0.14	0.03	0.12	0.56	0.26	0.59
35	87,268	87,268	Tr.9.1.1	17.6	0.020	0.07	0.02	0.08	0.33	0.15	0.35
41	81,397	233,880	Tr.9.1	18.8	0.038	0.08	0.02	0.11	0.42	0.19	0.43
40	9,817	243,698	Tr.9	18.7	0.042	0.08	0.01	0.11	0.42	0.19	0.43
39	**9,144**	**2,377,531**		**64.3**	**0.246**	**0.07**	**0.00**	**0.14**	**0.18**	**0.21**	**0.19**

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basins 17 include contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Table A 3.4a. APEX estimated annual average values at the edge-of-field (subarea) within the Red Deer River study area for Scenario 5 (Grassed Waterways). The AESA sub-basins are shown in bold.

Sub-basin	Modelled area (ha)	Runoff depth (mm)	TSS and nutrient export coefficients^z						
			TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
			(Mg ha^{-1})	------------------------------ (kg ha^{-1}) ------------------------------					
1	**35,394**	**61.8**	**0.057**	**0.46**	**0.09**	**0.32**	**0.72**	**0.78**	**0.81**
2	25,323	16.8	0.034	0.17	0.03	0.06	0.23	0.22	0.26
3	7,049	7.7	0.005	0.14	0.03	0.06	0.46	0.20	0.49
4	3,118	8.6	0.010	0.21	0.04	0.07	0.50	0.28	0.54
5	43,230	17.6	0.028	0.38	0.08	0.10	0.65	0.48	0.73
6	31,060	7.3	0.014	0.04	0.02	0.03	0.07	0.07	0.09
7	1,329	13.0	0.010	0.23	0.07	0.07	0.37	0.30	0.44
8	20,092	7.6	0.015	0.08	0.02	0.02	0.10	0.10	0.12
9	708	12.0	0.004	0.36	0.04	0.06	0.53	0.41	0.57
10	55,995	0.0	0.000	0.00	0.00	0.00	0.00	0.00	0.00
11	39,794	11.9	0.012	0.10	0.03	0.08	0.36	0.18	0.39
12	44,768	12.0	0.016	0.25	0.05	0.07	0.45	0.32	0.50
13	**17,445**	**14.9**	**0.002**	**0.11**	**0.02**	**0.34**	**0.24**	**0.45**	**0.25**
14	20,514	11.7	0.005	0.12	0.03	0.07	0.37	0.19	0.40
15	33,842	3.8	0.007	0.04	0.01	0.02	0.07	0.06	0.09
16	2,763	15.2	0.010	0.18	0.04	0.03	0.20	0.21	0.24
17	4,729	15.1	0.016	0.30	0.05	0.05	0.54	0.35	0.59
18	53,062	11.1	0.018	0.17	0.03	0.06	0.30	0.23	0.33
19	35,641	14.5	0.017	0.15	0.03	0.06	0.39	0.21	0.43
20	29,237	14.9	0.017	0.22	0.04	0.06	0.42	0.28	0.46
21	13,177	11.6	0.017	0.20	0.04	0.09	0.40	0.30	0.45
22	2,673	11.4	0.009	0.24	0.04	0.12	0.47	0.36	0.52
23	13,496	12.0	0.010	0.21	0.04	0.10	0.49	0.30	0.53
24	**4,523**	**26.7**	**0.005**	**0.07**	**0.01**	**0.19**	**0.31**	**0.26**	**0.32**
25	**15,379**	**26.0**	**0.007**	**0.11**	**0.02**	**0.25**	**0.39**	**0.36**	**0.40**
26	66,468	12.6	0.021	0.18	0.04	0.07	0.28	0.26	0.33
27	45,708	7.4	0.016	0.10	0.03	0.04	0.10	0.14	0.13
28	38,123	12.4	0.026	0.12	0.03	0.07	0.25	0.19	0.28
29	17,446	15.8	0.028	0.21	0.04	0.14	0.28	0.34	0.32
30	25,153	13.6	0.022	0.25	0.05	0.11	0.39	0.36	0.44
31	9,073	9.3	0.013	0.10	0.02	0.08	0.25	0.18	0.27
32	**5,796**	**19.8**	**0.004**	**0.03**	**0.01**	**0.19**	**0.16**	**0.22**	**0.17**
33	38,032	19.7	0.016	0.33	0.06	0.11	0.28	0.43	0.34
34	65,215	24.4	0.022	0.14	0.04	0.12	0.55	0.26	0.58
35	87,268	18.3	0.018	0.08	0.02	0.09	0.35	0.17	0.37
36	55,237	18.9	0.026	0.16	0.03	0.11	0.21	0.27	0.24
37	60,650	20.0	0.027	0.16	0.04	0.07	0.09	0.23	0.13
38	19,016	20.1	0.018	0.17	0.02	0.07	0.14	0.24	0.17
39	9,144	21.5	0.019	0.29	0.04	0.10	0.22	0.39	0.26
40	9,817	17.7	0.013	0.45	0.08	0.15	0.33	0.59	0.41
41	81,397	16.7	0.012	0.10	0.02	0.12	0.38	0.21	0.40

^{z} TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

Table A3.4b. SWAPP estimated cumulative environmental results at the outlet of each sub-basin for Scenario 5 (Grassed Waterway). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Runoff depth	TSS and nutrient export coefficients[z]						
	Individual	Cumulative			TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			(mm)	(Mg ha^{-1})	-------------------- (kg ha^{-1}) --------------------					
17	4,729	1,164,729[y]		114.0	0.049	0.42	0.03	0.09	0.03	0.50	0.06
19	35,641	35,641	Tr.1	14.5	0.019	0.12	0.02	0.06	0.40	0.18	0.42
16	6,541	1,206,912		112.1	0.096	0.34	0.02	0.20	0.05	0.54	0.07
1	35,394	35,394	Tr.2.2.2	61.8	0.057	0.37	0.07	0.32	0.74	0.69	0.81
2	25,323	25,323	Tr.2.2.1	16.8	0.039	0.13	0.02	0.06	0.24	0.19	0.26
5	43,230	103,947	Tr.2.2	32.5	0.059	0.26	0.04	0.16	0.59	0.42	0.63
8	29,263	29,263	Tr.2.1.1	5.3	0.010	0.04	0.01	0.01	0.07	0.06	0.08
9	708	29,971	Tr.2.1	5.4	0.002	0.04	0.01	0.01	0.08	0.05	0.09
12	44,768	178,686	Tr.2	22.8	0.051	0.18	0.03	0.11	0.48	0.29	0.51
20	29,238	1,414,835		98.8	0.164	0.26	0.02	0.18	0.12	0.44	0.14
18	53,062	1,467,897		95.7	0.196	0.20	0.01	0.18	0.13	0.38	0.14
13	17,445	17,445	Tr.3	15.0	0.003	0.09	0.01	0.34	0.24	0.43	0.25
14	20,514	1,505,856		93.6	0.233	0.16	0.01	0.18	0.14	0.34	0.15
3	7,049	7,049	Tr.4.1.1.1.1.1	7.7	0.006	0.12	0.02	0.06	0.47	0.18	0.49
4	3,118	10,167	Tr.4.1.1.1.1	8.0	0.007	0.12	0.02	0.06	0.48	0.18	0.50
11	39,794	49,961	Tr.4.1.1.1	11.2	0.013	0.08	0.02	0.07	0.38	0.15	0.40
6	31,060	81,020	Tr.4.1.1	9.7	0.015	0.06	0.01	0.05	0.27	0.11	0.28
7	1,329	82,349	Tr.4.1	9.8	0.003	0.05	0.01	0.03	0.26	0.09	0.28
10	72,691	155,040	Tr.4	5.2	0.001	0.03	0.01	0.01	0.14	0.04	0.14
15	33,842	33,842	Tr.5	3.8	0.008	0.03	0.01	0.02	0.08	0.05	0.09
26	66,468	1,761,206		81.0	0.259	0.12	0.01	0.16	0.14	0.28	0.15
21	13,177	13,177	Tr.6.1.1	11.7	0.017	0.17	0.03	0.09	0.41	0.26	0.45
22	2,673	15,850	Tr.6.1	11.7	0.004	0.15	0.03	0.07	0.41	0.23	0.44
27	45,708	61,558	Tr.6	8.5	0.018	0.09	0.02	0.05	0.19	0.14	0.21
30	25,153	25,153	Tr.7	13.7	0.028	0.21	0.04	0.11	0.40	0.32	0.44
33	38,032	1,885,950		76.5	0.272	0.10	0.01	0.15	0.15	0.26	0.16
24	4,523	4,523	Tr.8.2.2.1.1.1.1	26.8	0.005	0.06	0.01	0.19	0.31	0.25	0.32
25	15,379	19,902	Tr.8.2.2.1.1	26.2	0.007	0.08	0.01	0.24	0.37	0.32	0.38
29	17,446	37,348	Tr.8.2.2.1	21.4	0.020	0.11	0.02	0.19	0.33	0.31	0.35
31	9,073	46,422	Tr.8.2.2	19.1	0.006	0.10	0.01	0.14	0.32	0.24	0.33
32	5,796	5,796	Tr.8.2.1	19.8	0.004	0.02	0.00	0.19	0.17	0.21	0.17
36	55,237	107,454	Tr.8.2	19.0	0.032	0.10	0.02	0.13	0.26	0.23	0.28
23	13,496	13,496	Tr.8.1.1	12.1	0.010	0.17	0.03	0.10	0.50	0.27	0.53
28	38,123	51,619	Tr.8.1	12.4	0.025	0.11	0.02	0.07	0.32	0.18	0.34
37	60,650	219,724	Tr.8	17.7	0.039	0.10	0.02	0.10	0.23	0.20	0.25
38	19,016	2,124,690		72.2	0.267	0.09	0.01	0.16	0.21	0.25	0.22
34	65,215	65,215	Tr.9.1.2	24.5	0.030	0.12	0.03	0.12	0.56	0.23	0.58
35	87,268	87,268	Tr.9.1.1	18.3	0.020	0.07	0.02	0.09	0.36	0.16	0.37
41	81,397	233,880	Tr.9.1	19.5	0.038	0.08	0.01	0.10	0.43	0.18	0.44
40	9,817	243,698	Tr.9	19.4	0.042	0.08	0.01	0.11	0.42	0.18	0.44
39	**9,144**	**2,377,531**		**64.6**	**0.247**	**0.07**	**0.00**	**0.14**	**0.19**	**0.21**	**0.20**

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Table A3.5a APEX estimated annual average values at the edge-of-field (subarea) within the Red Deer River study area for Scenario 6 (Riparian Setbacks). The AESA sub-basins are shown in bold.

	Modelled	Runoff	TSS and nutrient export coefficients^z						
Sub-basin	area (ha)	depth (mm)	TSS (Mg ha^{-1})	ON	OP	NO_3-N	PO_4-P	TN	TP
				---------------------------------- (kg ha^{-1}) ----------------------------------					
1	**35,394**	**60.3**	**0.055**	**0.49**	**0.10**	**0.28**	**0.67**	**0.76**	**0.77**
2	25,323	16.6	0.033	0.15	0.03	0.05	0.21	0.20	0.24
3	7,049	6.3	0.005	0.13	0.03	0.03	0.31	0.16	0.34
4	3,118	8.6	0.010	0.21	0.04	0.07	0.50	0.28	0.54
5	43,230	17.4	0.029	0.38	0.07	0.08	0.59	0.45	0.67
6	31,060	5.6	0.010	0.02	0.01	0.01	0.04	0.04	0.05
7	1,329	12.0	0.007	0.21	0.06	0.04	0.30	0.26	0.36
8	20,092	7.2	0.014	0.07	0.02	0.01	0.08	0.09	0.09
9	708	12.0	0.004	0.36	0.04	0.06	0.53	0.41	0.57
10	55,995	0.0	0.000	0.00	0.00	0.00	0.00	0.00	0.00
11	39,794	10.6	0.010	0.09	0.02	0.05	0.26	0.14	0.28
12	44,768	11.4	0.017	0.25	0.05	0.05	0.37	0.29	0.42
13	**17,445**	**16.1**	**0.003**	**0.09**	**0.02**	**0.34**	**0.25**	**0.42**	**0.26**
14	20,514	9.9	0.004	0.12	0.02	0.04	0.26	0.15	0.28
15	33,842	1.5	0.003	0.01	0.00	0.00	0.02	0.02	0.02
16	2,763	14.7	0.008	0.17	0.04	0.02	0.19	0.19	0.23
17	4,729	13.2	0.012	0.28	0.04	0.03	0.43	0.30	0.47
18	53,062	8.2	0.012	0.12	0.02	0.02	0.16	0.14	0.18
19	35,641	11.9	0.012	0.13	0.03	0.03	0.28	0.16	0.30
20	29,237	12.5	0.012	0.20	0.03	0.03	0.31	0.22	0.34
21	13,177	10.2	0.012	0.16	0.04	0.07	0.31	0.23	0.35
22	2,673	9.7	0.006	0.22	0.04	0.08	0.35	0.30	0.39
23	13,496	10.2	0.008	0.18	0.03	0.06	0.37	0.24	0.41
24	**4,523**	**28.8**	**0.006**	**0.07**	**0.01**	**0.22**	**0.33**	**0.29**	**0.34**
25	**15,379**	**26.3**	**0.007**	**0.12**	**0.02**	**0.23**	**0.37**	**0.35**	**0.39**
26	66,468	10.4	0.016	0.13	0.03	0.05	0.19	0.17	0.22
27	45,708	5.7	0.012	0.07	0.02	0.02	0.06	0.09	0.08
28	38,123	10.5	0.021	0.09	0.03	0.05	0.18	0.14	0.21
29	17,446	14.4	0.022	0.17	0.04	0.11	0.22	0.29	0.25
30	25,153	10.0	0.015	0.15	0.04	0.06	0.22	0.22	0.26
31	9,073	8.9	0.011	0.08	0.01	0.07	0.23	0.15	0.24
32	**5,796**	**19.8**	**0.004**	**0.03**	**0.01**	**0.19**	**0.16**	**0.22**	**0.17**
33	38,032	19.4	0.014	0.30	0.05	0.10	0.27	0.40	0.33
34	65,215	24.0	0.021	0.13	0.03	0.11	0.53	0.24	0.57
35	87,268	17.1	0.013	0.06	0.02	0.07	0.29	0.12	0.31
36	55,237	18.4	0.024	0.11	0.03	0.10	0.19	0.22	0.22
37	60,650	21.7	0.032	0.18	0.05	0.07	0.10	0.25	0.14
38	19,016	19.5	0.015	0.16	0.02	0.06	0.14	0.22	0.16
39	9,144	21.4	0.017	0.28	0.03	0.10	0.22	0.37	0.26
40	9,817	17.1	0.009	0.43	0.07	0.11	0.29	0.53	0.36
41	81,397	16.0	0.010	0.09	0.02	0.10	0.36	0.20	0.38

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

Table A3.5b. SWAPP estimated cumulative environmental results at the outlet of each sub-basin for Scenario 6 (Riparian Setbacks). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Flow depth	TSS and nutrient export coefficients[z]						
	Individual	Cumulative			TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			(mm)	(Mg ha^{-1})	------------------ (kg ha^{-1}) ------------------					
17	4,729	1,164,729[y]		114.0	0.049	0.42	0.03	0.09	0.03	0.50	0.06
19	35,641	35,641	Tr.1	11.9	0.013	0.10	0.02	0.03	0.28	0.13	0.30
16	6,541	1,206,912		112.0	0.096	0.34	0.02	0.20	0.05	0.54	0.07
1	35,394	35,394	Tr.2.2.2	60.3	0.055	0.40	0.07	0.28	0.69	0.67	0.76
2	25,323	25,323	Tr.2.2.1	16.6	0.037	0.12	0.02	0.05	0.22	0.17	0.24
5	43,230	103,947	Tr.2.2	31.8	0.058	0.26	0.04	0.14	0.55	0.40	0.59
8	29,263	29,263	Tr.2.1.1	5.0	0.010	0.04	0.01	0.01	0.06	0.05	0.06
9	708	29,971	Tr.2.1	5.2	0.002	0.04	0.01	0.00	0.07	0.05	0.07
12	44,768	178,686	Tr.2	22.2	0.051	0.18	0.03	0.09	0.43	0.27	0.46
20	29,238	1,414,835		98.6	0.164	0.25	0.02	0.18	0.11	0.44	0.12
18	53,062	1,467,897		95.4	0.195	0.20	0.01	0.17	0.11	0.38	0.13
13	17,445	17,445	Tr.3	16.2	0.003	0.07	0.01	0.34	0.25	0.41	0.26
14	20,514	1,505,856		93.3	0.232	0.16	0.01	0.17	0.12	0.34	0.13
3	7,049	7,049	Tr.4.1.1.1.1.1	6.3	0.005	0.11	0.02	0.03	0.32	0.13	0.34
4	3,118	10,167	Tr.4.1.1.1.1	7.0	0.007	0.11	0.02	0.04	0.38	0.15	0.40
11	39,794	49,961	Tr.4.1.1.1	9.9	0.011	0.08	0.02	0.04	0.28	0.12	0.29
6	31,060	81,020	Tr.4.1.1	8.3	0.012	0.05	0.01	0.03	0.19	0.08	0.20
7	1,329	82,349	Tr.4.1	8.3	0.002	0.04	0.01	0.02	0.19	0.06	0.20
10	72,691	155,040	Tr.4	4.4	0.001	0.02	0.00	0.00	0.10	0.03	0.10
15	33,842	33,842	Tr.5	1.5	0.003	0.01	0.00	0.00	0.02	0.01	0.02
26	66,468	1,761,206		80.6	0.257	0.12	0.01	0.15	0.12	0.27	0.13
21	13,177	13,177	Tr.6.1.1	10.2	0.013	0.14	0.03	0.07	0.32	0.20	0.35
22	2,673	15,850	Tr.6.1	10.2	0.003	0.13	0.02	0.05	0.32	0.18	0.34
27	45,708	61,558	Tr.6	6.9	0.014	0.07	0.02	0.03	0.13	0.10	0.15
30	25,153	25,153	Tr.7	10.0	0.020	0.13	0.03	0.06	0.23	0.19	0.26
33	38,032	1,885,950		76.0	0.270	0.10	0.01	0.15	0.13	0.24	0.13
24	4,523	4,523	Tr.8.2.2.1.1.1.1	28.8	0.006	0.05	0.01	0.22	0.33	0.28	0.34
25	15,379	19,902	Tr.8.2.2.1.1	26.9	0.007	0.08	0.01	0.23	0.37	0.31	0.38
29	17,446	37,348	Tr.8.2.2.1	21.1	0.018	0.10	0.02	0.18	0.30	0.28	0.32
31	9,073	46,422	Tr.8.2.2	18.7	0.006	0.09	0.01	0.13	0.28	0.22	0.30
32	5,796	5,796	Tr.8.2.1	19.8	0.004	0.02	0.00	0.19	0.17	0.21	0.17
36	55,237	107,454	Tr.8.2	18.6	0.030	0.08	0.01	0.12	0.23	0.20	0.25
23	13,496	13,496	Tr.8.1.1	10.3	0.009	0.15	0.03	0.06	0.38	0.21	0.40
28	38,123	51,619	Tr.8.1	10.5	0.020	0.09	0.02	0.04	0.23	0.13	0.25
37	60,650	219,724	Tr.8	17.5	0.039	0.09	0.02	0.09	0.20	0.18	0.22
38	19,016	2,124,690		71.6	0.264	0.09	0.01	0.15	0.18	0.24	0.19
34	65,215	65,215	Tr.9.1.2	24.1	0.029	0.11	0.03	0.11	0.54	0.22	0.57
35	87,268	87,268	Tr.9.1.1	17.1	0.015	0.05	0.01	0.07	0.30	0.11	0.31
41	81,397	233,880	Tr.9.1	18.7	0.034	0.07	0.01	0.09	0.39	0.16	0.40
40	9,817	243,698	Tr.9	18.6	0.039	0.07	0.01	0.09	0.39	0.16	0.40
39	**9,144**	**2,377,531**		**64.0**	**0.244**	**0.06**	**0.00**	**0.13**	**0.16**	**0.20**	**0.17**

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Table A3.6a. APEX estimated annual average values at the edge-of-field (subarea) within the Red Deer River study area for Scenario 7 (Wetland Restoration). The AESA sub-basins are shown in bold.

Sub-basin	Modelled area	Runoff depth	TSS and nutrient export coefficients						
			TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	(ha)	(mm)	(Mg ha^{-1})	------------------------------- (kg ha^{-1}) --------------------------------					
1	**35,394**	**60.2**	**0.047**	**0.68**	**0.21**	**0.30**	**0.68**	**0.99**	**0.90**
2	25,323	17.2	0.032	0.16	0.04	0.06	0.23	0.21	0.27
3	7,049	7.6	0.005	0.14	0.03	0.06	0.45	0.20	0.49
4	3,118	8.6	0.010	0.21	0.04	0.07	0.50	0.28	0.54
5	43,230	18.5	0.031	0.39	0.08	0.10	0.67	0.49	0.75
6	31,060	7.0	0.013	0.04	0.02	0.03	0.07	0.06	0.09
7	1,329	13.0	0.010	0.23	0.07	0.07	0.37	0.30	0.44
8	20,092	7.9	0.015	0.08	0.02	0.02	0.10	0.10	0.12
9	708	12.0	0.004	0.36	0.04	0.06	0.53	0.41	0.57
10	55,995	0.0	0.000	0.00	0.00	0.00	0.00	0.00	0.00
11	39,794	11.9	0.012	0.09	0.03	0.08	0.35	0.17	0.38
12	44,768	12.4	0.020	0.25	0.05	0.07	0.46	0.32	0.50
13	**17,445**	**17.9**	**0.003**	**0.10**	**0.02**	**0.41**	**0.30**	**0.51**	**0.32**
14	20,514	11.3	0.005	0.13	0.03	0.06	0.36	0.19	0.38
15	33,842	3.4	0.006	0.03	0.01	0.02	0.07	0.05	0.08
16	2,763	14.7	0.009	0.18	0.04	0.02	0.19	0.20	0.22
17	4,729	15.1	0.016	0.30	0.05	0.05	0.54	0.35	0.59
18	53,062	10.7	0.018	0.16	0.03	0.05	0.29	0.22	0.32
19	35,641	14.5	0.017	0.15	0.03	0.06	0.39	0.21	0.43
20	29,237	14.8	0.017	0.22	0.04	0.05	0.42	0.28	0.46
21	13,177	10.1	0.015	0.17	0.04	0.08	0.34	0.25	0.38
22	2,673	10.8	0.009	0.23	0.04	0.12	0.47	0.35	0.51
23	13,496	12.1	0.008	0.21	0.04	0.10	0.49	0.31	0.53
24	**4,523**	**30.5**	**0.007**	**0.09**	**0.02**	**0.27**	**0.36**	**0.35**	**0.38**
25	**15,379**	**28.5**	**0.008**	**0.10**	**0.01**	**0.27**	**0.42**	**0.38**	**0.44**
26	66,468	11.9	0.022	0.16	0.04	0.07	0.24	0.23	0.28
27	45,708	6.2	0.014	0.08	0.03	0.03	0.08	0.11	0.11
28	38,123	11.8	0.025	0.12	0.03	0.06	0.23	0.18	0.26
29	17,446	15.4	0.028	0.21	0.04	0.13	0.26	0.34	0.30
30	25,153	12.7	0.022	0.22	0.05	0.10	0.34	0.32	0.40
31	9,073	9.0	0.013	0.09	0.02	0.08	0.24	0.17	0.26
32	**5,796**	**19.8**	**0.004**	**0.03**	**0.01**	**0.19**	**0.16**	**0.22**	**0.17**
33	38,032	20.6	0.023	0.38	0.07	0.14	0.31	0.52	0.38
34	65,215	25.9	0.030	0.17	0.04	0.14	0.62	0.32	0.67
35	87,268	17.9	0.018	0.08	0.02	0.08	0.33	0.16	0.35
36	55,237	18.4	0.026	0.15	0.03	0.10	0.18	0.25	0.21
37	60,650	21.3	0.033	0.17	0.04	0.06	0.08	0.23	0.12
38	19,016	19.4	0.021	0.21	0.03	0.06	0.13	0.27	0.16
39	9,144	21.4	0.022	0.32	0.04	0.11	0.23	0.43	0.27
40	9,817	17.5	0.013	0.44	0.08	0.15	0.33	0.59	0.40
41	81,397	16.3	0.014	0.10	0.02	0.13	0.37	0.22	0.39

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

Table A3.6b. SWAPP estimated cumulative environmental results at the outlet of each sub-basin for Scenario 7 (Wetland Restoration). The Red Deer River study area outlet is shown in bold.

Sub-basin ID	Modelled area		Tributary (Tr) ID	Runoff depth	TSS and nutrient export coefficients[z]						
	Individual	Cumulative			TSS	ON	OP	NO_3-N	PO_4-P	TN	TP
	-------- (ha) --------			(mm)	(Mg ha^{-1})	------------------ (kg ha^{-1}) ---------------------					
17	4,729	1,164,729[y]		114.0	0.049	0.42	0.03	0.09	0.03	0.50	0.06
19	35,641	35,641	Tr.1	14.5	0.019	0.12	0.02	0.06	0.40	0.18	0.42
16	6,541	1,206,912		112.1	0.096	0.34	0.02	0.20	0.05	0.54	0.07
1	35,394	35,394	Tr.2.2.2	60.2	0.047	0.56	0.15	0.30	0.73	0.86	0.89
2	25,323	25,323	Tr.2.2.1	17.2	0.036	0.13	0.03	0.06	0.24	0.18	0.27
5	43,230	103,947	Tr.2.2	32.4	0.055	0.31	0.06	0.16	0.61	0.47	0.67
8	29,263	29,263	Tr.2.1.1	5.4	0.010	0.05	0.01	0.01	0.07	0.06	0.08
9	708	29,971	Tr.2.1	5.6	0.002	0.04	0.01	0.01	0.08	0.05	0.09
12	44,768	178,686	Tr.2	22.9	0.050	0.20	0.04	0.11	0.49	0.31	0.53
20	29,238	1,414,835		98.8	0.164	0.26	0.02	0.18	0.12	0.44	0.14
18	53,062	1,467,897		95.6	0.195	0.21	0.01	0.18	0.13	0.39	0.14
13	17,445	17,445	Tr.3	18.0	0.004	0.08	0.01	0.40	0.30	0.49	0.31
14	20,514	1,505,856		93.6	0.233	0.17	0.01	0.18	0.14	0.35	0.15
3	7,049	7,049	Tr.4.1.1.1.1.1	7.7	0.006	0.12	0.02	0.06	0.46	0.17	0.48
4	3,118	10,167	Tr.4.1.1.1.1	8.0	0.007	0.12	0.02	0.06	0.48	0.18	0.50
11	39,794	49,961	Tr.4.1.1.1	11.2	0.012	0.08	0.02	0.07	0.37	0.15	0.39
6	31,060	81,020	Tr.4.1.1	9.6	0.014	0.05	0.01	0.05	0.26	0.10	0.27
7	1,329	82,349	Tr.4.1	9.7	0.003	0.05	0.01	0.03	0.26	0.08	0.27
10	72,691	155,040	Tr.4	5.1	0.001	0.02	0.00	0.01	0.13	0.03	0.14
15	33,842	33,842	Tr.5	3.4	0.007	0.03	0.01	0.02	0.07	0.04	0.08
26	66,468	1,761,206		81.0	0.259	0.12	0.01	0.16	0.14	0.28	0.15
21	13,177	13,177	Tr.6.1.1	10.2	0.016	0.14	0.03	0.08	0.34	0.22	0.37
22	2,673	15,850	Tr.6.1	10.3	0.003	0.13	0.02	0.07	0.36	0.20	0.38
27	45,708	61,558	Tr.6	7.3	0.016	0.08	0.02	0.04	0.16	0.11	0.18
30	25,153	25,153	Tr.7	12.8	0.026	0.18	0.04	0.10	0.35	0.28	0.39
33	38,032	1,885,950		76.5	0.272	0.10	0.01	0.15	0.15	0.26	0.16
24	4,523	4,523	Tr.8.2.2.1.1.1.1	30.6	0.007	0.07	0.01	0.26	0.36	0.33	0.37
25	15,379	19,902	Tr.8.2.2.1.1	29.0	0.008	0.08	0.01	0.27	0.41	0.35	0.42
29	17,446	37,348	Tr.8.2.2.1	22.7	0.021	0.11	0.02	0.20	0.34	0.32	0.36
31	9,073	46,422	Tr.8.2.2	20.0	0.006	0.10	0.01	0.15	0.32	0.25	0.34
32	5,796	5,796	Tr.8.2.1	19.8	0.004	0.02	0.00	0.19	0.17	0.21	0.17
36	55,237	107,454	Tr.8.2	19.2	0.031	0.10	0.02	0.13	0.24	0.23	0.26
23	13,496	13,496	Tr.8.1.1	12.1	0.009	0.17	0.03	0.10	0.50	0.27	0.53
28	38,123	51,619	Tr.8.1	11.9	0.024	0.11	0.02	0.06	0.30	0.17	0.32
37	60,650	219,724	Tr.8	18.0	0.041	0.10	0.02	0.09	0.22	0.19	0.23
38	19,016	2,124,690		72.1	0.267	0.09	0.01	0.16	0.21	0.25	0.22
34	65,215	65,215	Tr.9.1.2	25.9	0.038	0.14	0.03	0.14	0.63	0.29	0.66
35	87,268	87,268	Tr.9.1.1	17.9	0.020	0.06	0.02	0.08	0.33	0.15	0.35
41	81,397	233,880	Tr.9.1	19.6	0.040	0.08	0.02	0.11	0.43	0.19	0.45
40	9,817	243,698	Tr.9	19.5	0.044	0.08	0.01	0.12	0.43	0.19	0.45
39	**9,144**	**2,377,531**		**64.5**	**0.247**	**0.07**	**0.00**	**0.14**	**0.19**	**0.21**	**0.20**

[z] TSS = total suspended solids, ON = organic nitrogen, OP = organic phosphorus, NO_3-N = nitrate nitrogen, PO_4-P = phosphate phosphorus, TN = total nitrogen, TP = total phosphorus.

[y] Sub-basin 17 includes contribution of the upstream area (1,160,000 ha) of the RDR Watershed.

Appendix 4. Summary of economic results for sub-basins in the Red Deer River study area.

Table A4.1. Change in annual net returns for Scenarios 2, 3, and 4 compared to the Baseline scenario by sub-basin in Red Deer River study area.

		Scenario 2: Manure agronomic phosphorus management		Scenario 3: Rotational grazing and controlled access		Scenario 4: Seasonal bedding and feeding sites	
Census sub-basins	Average size (ha)	Total net return $(\$\ \mathrm{yr}^{-1})$	Total net return $(\$\ \mathrm{ha}^{-1}\mathrm{yr}^{-1})$	Total net return $(\$\ \mathrm{yr}^{-1})$	Total net return $(\$\ \mathrm{ha}^{-1}\mathrm{yr}^{-1})$	Total net return $(\$\ \mathrm{yr}^{-1})$	Total net return $(\$\ \mathrm{ha}^{-1}\mathrm{yr}^{-1})$
154	205	1703	8.30	3973	19.36	-236	-1.15
157	76	-284	-3.72	877	11.48	-84	-1.10
163	121	-338	-2.80	1967	16.28	-92	-0.76
165	91	1311	14.48	2042	22.56	-82	-0.90
168	214	1829	8.55	418	1.95	-246	-1.15
169	100	-392	-3.92	987	9.88	-54	-0.54
173	133	90	0.67	115	0.87	-68	-0.51
176	296	-1236	-4.17	389	1.31	-33	-0.11
178	141	-1158	-8.19	2143	15.16	-140	-0.99
180	293	31	0.10	0	0	0	0
183	92	-729	-7.91	402	4.36	-104	-1.13
187	85	0	0	166	1.95	-98	-1.15
191	165	-914	-5.55	54	0.33	-32	-0.19
193	177	-976	-5.50	397	2.24	-37	-0.21
197	177	237	1.34	182	1.03	-10	-0.06
198	458	-549	-1.20	0	0	0	0
200	247	6	0.02	210	0.85	-124	-0.50
206	150	1313	8.77	120	0.80	-70	-0.47
207	224	102	0.46	138	0.62	-14	-0.06
209	491	0	0	0	0	0	0
213	365	-183	-0.50	94	0.26	-10	-0.03
217	196	2987	15.27	0	0	0	0
10046	101	-234	-2.32	15	0.15	-9	-0.09

Table A4.2. Change in annual net returns for Scenarios 5, 6, and 7 compared to the Baseline Scenario by sub-basin in Red Deer River study area.

		Scenario 5: Grassed waterways		Scenario 6: Riparian setbacks		Scenario 7: Wetland restoration	
Census sub-basins	Average size (ha)	Total net return $(\$\ \mathrm{yr}^{-1})$	Total net return $(\$\ \mathrm{ha}^{-1}\mathrm{yr}^{-1})$	Total net return $(\$\ \mathrm{yr}^{-1})$	Total net return $(\$\ \mathrm{ha}^{-1}\mathrm{yr}^{-1})$	Total net return $(\$\ \mathrm{yr}^{-1})$	Total net return $(\$\ \mathrm{ha}^{-1}\mathrm{yr}^{-1})$
154	205	-384	-1.87	-722	-3.52	-575	-2.80
157	76	-229	-3.00	-386	-5.05	-329	-4.30
163	121	-396	-3.27	-634	-5.25	-532	-4.41
165	91	-360	-3.98	-606	-6.69	-477	-5.27
168	214	-300	-1.40	-609	-2.85	-487	-2.28
169	100	-474	-4.75	-757	-7.58	-605	-6.06
173	133	-303	-2.27	-616	-4.61	-455	-3.41
176	296	-749	-2.53	-1270	-4.29	-964	-3.25
178	141	-322	-2.28	-593	-4.20	-476	-3.37
180	293	-909	-3.11	-1417	-4.84	-1131	-3.86
183	92	-139	-1.51	-344	-3.74	-262	-2.84
187	85	-190	-2.23	-390	-4.58	-313	-3.68
191	165	-710	-4.31	-1036	-6.29	-866	-5.26
193	177	-611	-3.44	-964	-5.44	-775	-4.37
197	177	-638	-3.61	-1018	-5.76	-798	-4.52
198	458	-1122	-2.45	-1813	-3.96	-1401	-3.06
200	247	-665	-2.69	-1093	-4.43	-873	-3.54
206	150	-354	-2.37	-683	-4.56	-515	-3.44
207	224	-873	-3.90	-1333	-5.96	-1062	-4.75
209	491	-1246	-2.54	-1881	-3.83	-1540	-3.14
213	365	-917	-2.51	-1482	-4.06	-1155	-3.17
217	196	-772	-3.95	-1177	-6.02	-957	-4.89
10046	101	-425	-4.21	-645	-6.38	-541	-5.36