Nutrient Beneficial Management Practices Evaluation Project

Summary and Recommendations

Alberta Government

ACIDF Alberta Crop Industry Development Fund Ltd.

Nutrient Beneficial Management Practices Evaluation Project

Summary and Recommendations

Paterson Earth & Water Consulting Ltd.
and
Alberta Agriculture and Rural Development

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EXECUTIVE SUMMARY

Introduction

Agriculture is Alberta's largest renewable industry, and generated more than $9 billion in exports in 2012, and represented 21% of Canada's total agri-food exports. Next to the energy sector, the agri-food industry is the most important driver of Alberta's economy. Alberta's agriculture industry generated almost $12 billion in total farm cash receipts in 2013, and employed about 230,000 Albertans. The total economic impact of Alberta's rural economy is estimated to be approximately $79 billion annually.

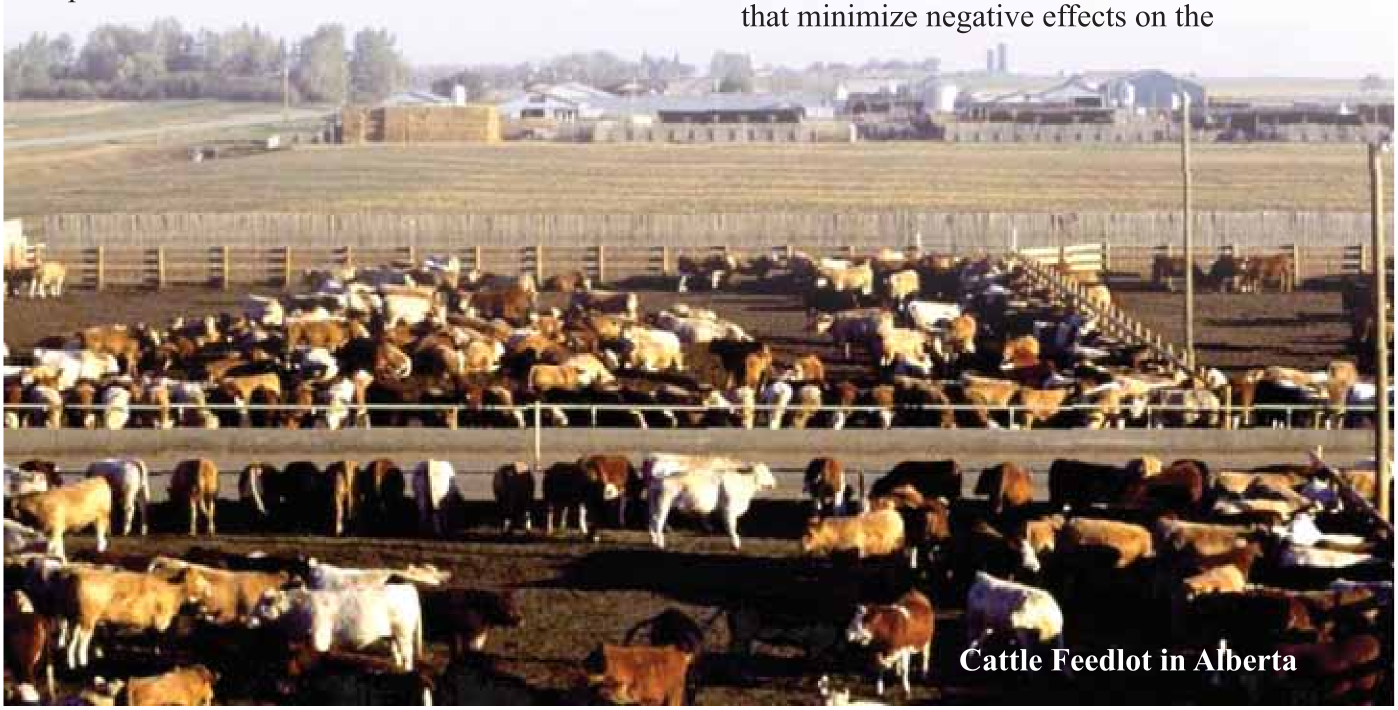
Alberta's crop and livestock producers face challenges every day with increasing input costs, market competition, and continued pressure to improve environmental stewardship. The risks to the environment from agriculture are many, with a major concern regarding impacts of agricultural management on water quality. Inversely, environmental events and poor surface water quality can negatively impact agricultural production.

In recent years, the impact of agriculture on the environment has focused on manure management related to livestock production, in particular the intensive livestock industry.

Manure is recognized as a beneficial source of nutrients and as a soil conditioner that can effectively decrease input costs. However, if not managed properly, manure application can lead to excess accumulation of nutrients and introduction of bacteria into the soil, which can then enter ground or surface water.

Producers increasingly recognize that environmental stewardship is a quality of life issue and a potential economic marketing opportunity. However, before investing, they are seeking proven management practices that will maintain efficient and viable farm operations while protecting the environment.

Beneficial management practices (BMPs) are defined as conservation practices, management techniques, or social actions that minimize negative effects on the



Cattle Feedlot in Alberta

environment, while being practical tools for producers to meet or exceed regulatory requirements and production targets. Numerous BMPs have been developed and promoted to minimize the impacts of agriculture on the environment and increase the sustainability of the agricultural industry.

Alberta Agriculture and Rural Development (ARD) completed a number of projects to assess the impacts of agricultural management practices on surface-water quality and identify solutions to mitigate the problem. These include:

- 1992 to 1997 - Canada-Alberta Environmentally Sustainable Agriculture Agreement (CAESA) water quality survey of 27 streams and 25 lakes in runoff-prone agricultural watersheds throughout Alberta;
- 1997 to 2007 - Alberta Environmentally Sustainable Agriculture (AESA) Water Quality Monitoring Project, which monitored and assessed water quality in 23 small agricultural watersheds in Alberta; and
- 1999 to 2007 - Alberta Soil Phosphorus Limits Project, which assessed the impacts of soil phosphorus (P) on surface-water quality and provided recommendations for P limits on agricultural lands in Alberta.

These studies are part of Alberta's "Agriculture Water Quality Mitigation" strategy, which recognizes the need for a step-wise, long-term strategy to understand the issues and identify practical mitigation options for agricultural producers (Figure 1).

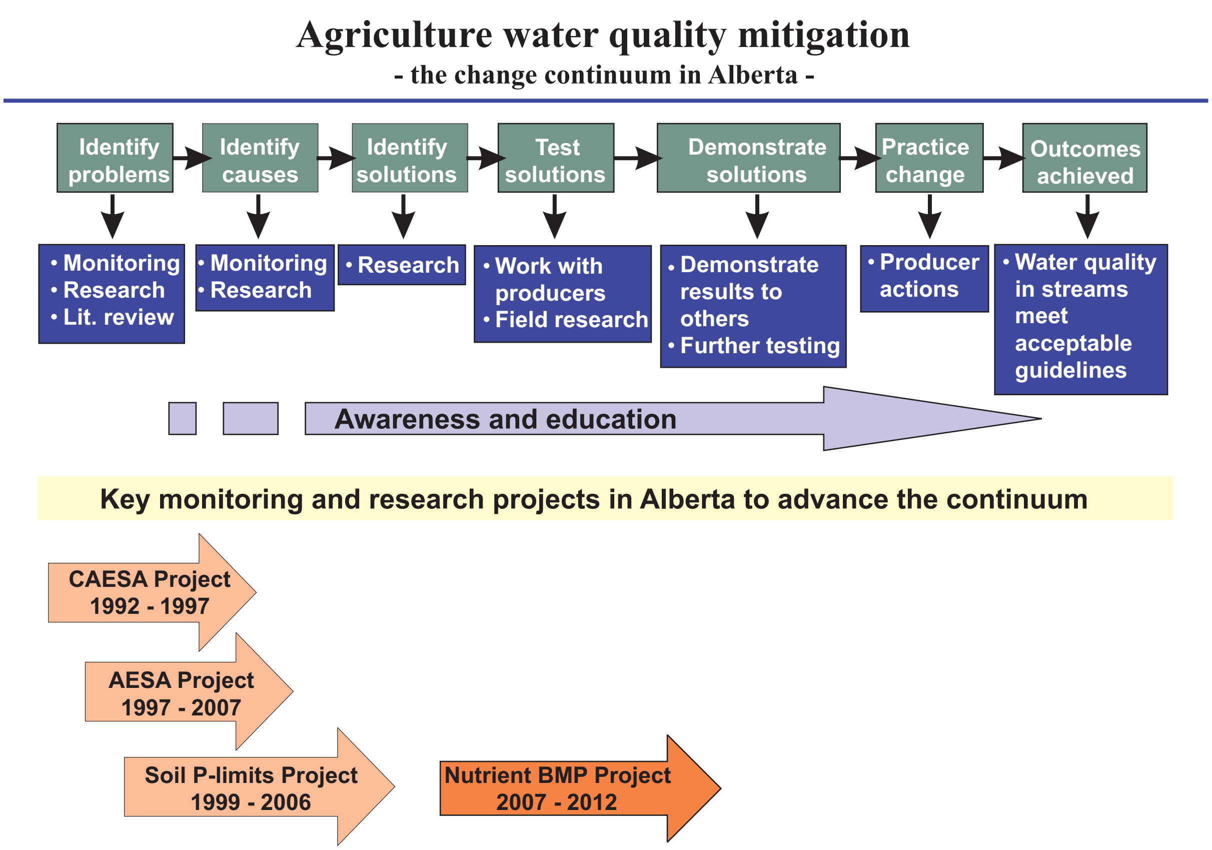


Figure 1. Schematic of agriculture water quality mitigation strategy for Alberta.

The earlier studies helped quantify the effects of agriculture on water quality and highlighted the need for field-scale BMPs. However, the effectiveness of field-scale BMPs was still unknown under Alberta conditions. Producers continue to request site-specific, risk-based tools to assist them in deciding which BMPs will yield the greatest environmental benefit for their financial investment. To address the need to better understand the effectiveness of BMPs, the Nutrient Beneficial Management Practices Evaluation Project (BMP Project) was initiated in 2007 to evaluate BMPs at field and watershed scales in Alberta.

Nutrient Beneficial Management Practices Evaluation Project

Alberta Agriculture and Rural Development and partners carried out the BMP Project from 2007 to 2012. The main objectives of the BMP Project were to:

- Evaluate the effectiveness of nutrient BMPs in reducing agricultural impacts on the environment at the farm scale;
- Assess the effects of BMPs on water quality in specific reaches of a watershed stream;
- Predict the cumulative effects of BMPs on the overall quality of a watershed stream using models;
- Evaluate nutrient BMPs for effective use of manure in crop production; and
- Assess economic costs and benefits associated with implemented BMPs.

The BMP Project is described in three volumes. This volume (Summary and Recommendations) provides the conclusions and recommendations from a tremendous amount of information collected and processed for the field and modelling studies. The detailed technical descriptions, data summaries, and interpretations are presented in Volume 2 for the Field Study and in Volume 3 for the Modelling Study. The latter volume is a compilation of three modelling reports.

Volume 1: Summary and Recommendations

Volume 2: Field Study

Volume 3: Modelling Study

- Application of the CEEOT Model to Alberta Watersheds
- Protocol for BMP Assessment
- Application of the CEEOT Model on the central portion of the Red Deer River Watershed

Field Research Study

The majority of the field research was carried out in two agricultural watersheds (Figure 2) in Alberta:

- Indianfarm Creek (IFC) Watershed (14,145 ha) in southwestern Alberta; and
- Whelp Creek (WHC) Sub-watershed (4595 ha) in central Alberta.

In addition, two irrigated field sites, with a history of heavy manure application, were selected in the:

- Battersea Drain Watershed (a 65-ha field); and
- Lower Little Bow Watershed (a 130-ha field).

A total of 22 BMP and reference sites were assessed within the selected watersheds. The IFC Watershed BMP sites are shown in Figure 3, WHC Sub-watershed BMP sites

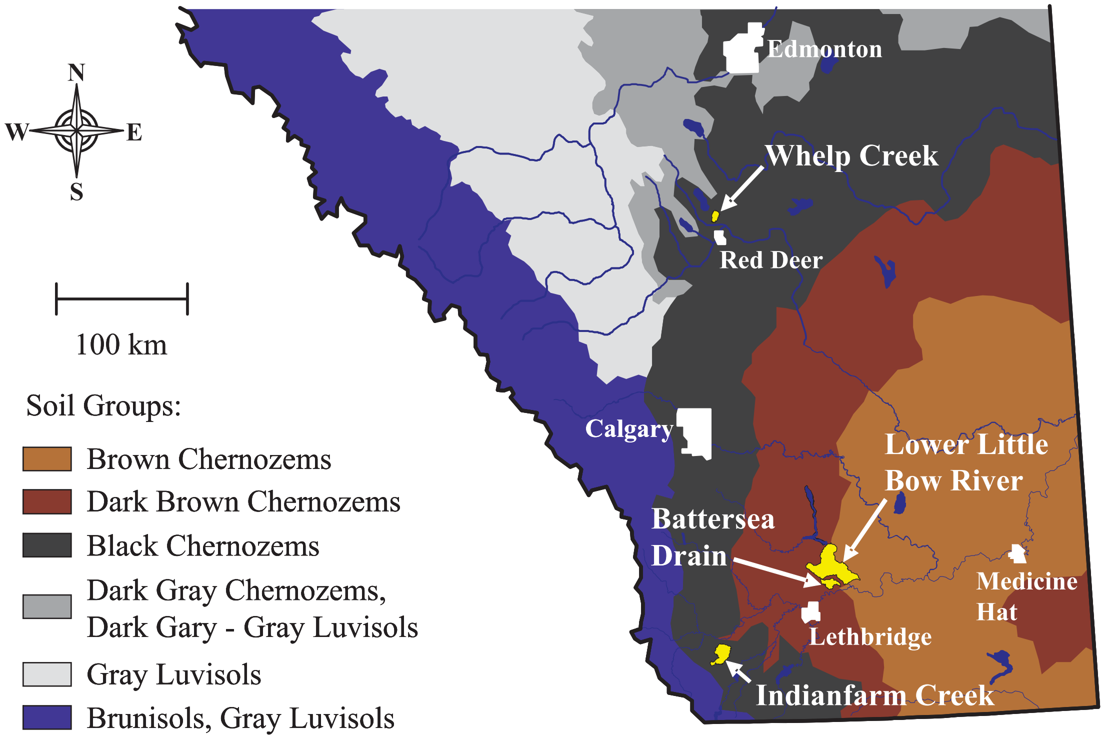


Figure 2. Location of the Nutrient Beneficial Management Practices Evaluaton Project research sites.

are shown in Figure 4, and descriptions for all sites are in Table 1. The BMP plan for each site included a suite of BMPs that were specifically designed to mitigate existing water quality concerns. The BMP sites were grouped into three general management categories.

- **Cattle management**: BMPs included infrastructure alterations; off-stream watering; windbreaks; fencing; and/or improved grazing management plans.
- **Manure nutrient management**: BMPs included cropland and nutrient management plans; setback areas from water bodies; and/or grassed waterways.
- **Surface-water management**: BMPs included berming and re-directing surface-water flow around feedlots; and irrigation pivot modification for variable rates and locations, and irrigation scheduling.

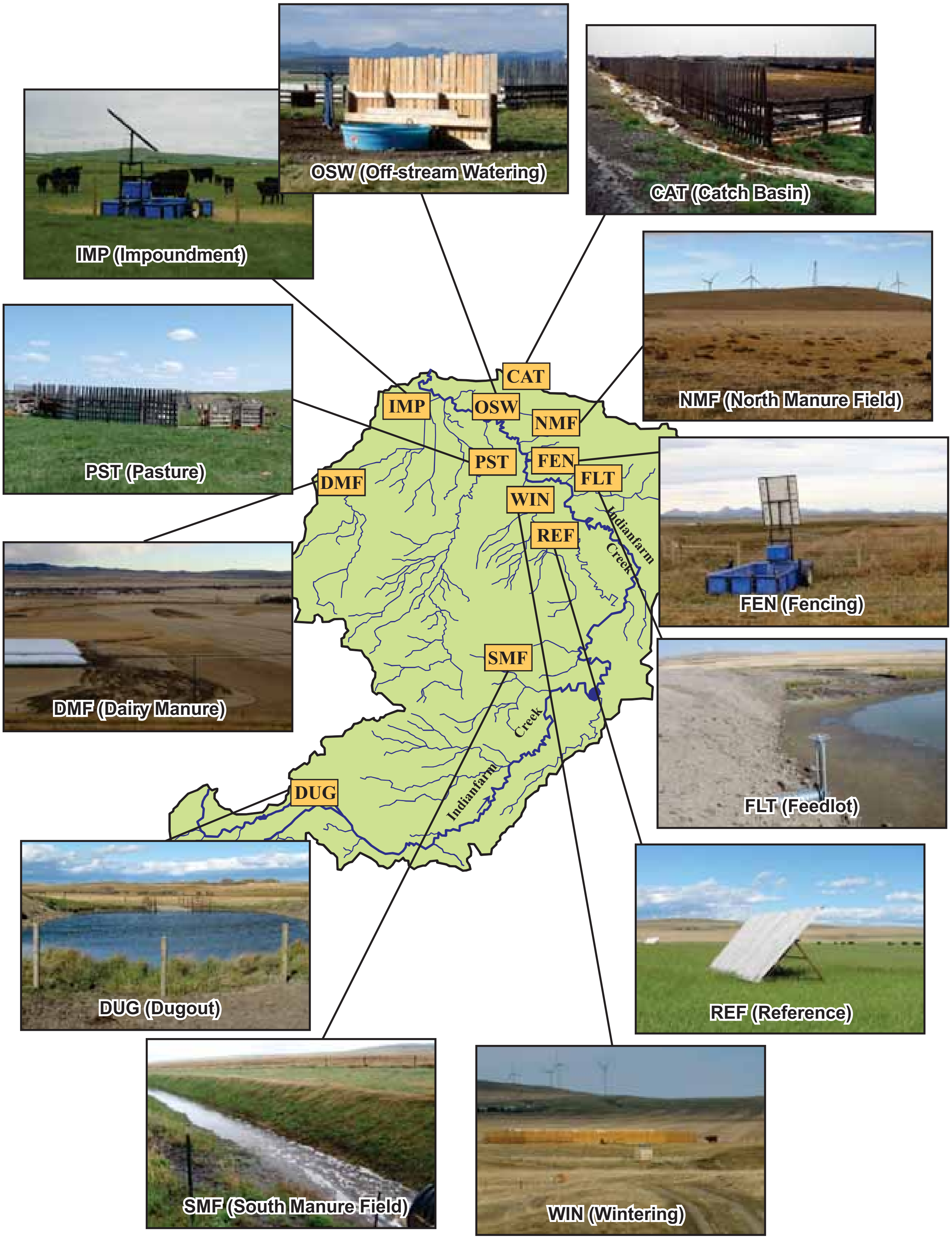


Figure 3. Overview of beneficial management practices sites in the Indianfarm Creek Watershed.

Figure 4. Overview of beneficial management practices sites in the Whelp Creek Sub-watershed.

Table 1. Beneficial management practices (BMP) sites and BMP plan descriptions.

			Indianfarm Creek Watershed
Impoundment	IMP[z]	C[y]	Cattle distribution control with fencing, off-stream watering, portable windbreak, bioengineering.[x]
Wintering	WIN	C	Wintering site relocation, cattle distribution control, grazing management, off-stream watering, bioengineering.[x]
Pasture	PST	C	Corral removal, grazing management, windbreaks, off-stream watering, bioengineering.[x]
Dairy Manure Field	DMF	N	Nutrient management plan, stop applying manure.
North Manure Field	NMF	C	Cattle distribution control during fall grazing.
South Manure Field	SMF[w]	N	
Reference	REF	C	Cattle distribution control during fall grazing.
Dugout	DUG	C	Control access of cattle to dugouts with fencing, off-stream watering, improved cattle crossing with a bridge.
Off-stream Watering	OSW	C	Off-stream watering.
Feedlot	FLT	C,S	Relocation of bedding and feeding site from stream, redirect stream flow, improve berms around dugout and catch basin.
Catch Basin	CAT	S	Redirect surface runoff water away from feedlot.
Fencing	FEN	C	Prevent access to stream with fencing.
			Whelp Creek Sub-watershed
North Field	NFD	N	Nutrient management plan, setbacks.
West Field	WFD	N	Nutrient management plan, setbacks, switch from fall to spring manure application.
East Field	EFD[v]	N	Nutrient management plan, setbacks on a forage crop.
South Field	SFD	N	Nutrient management plan, setbacks, buffer zone.
North Pasture	NPS	C	Bioengineering, extended pasture rest.
South Pasture	SPS	C	Rotational grazing management with new fencing and water system.
Reference 1	REF 1		Non-BMP, non -manure monitoring site.
Reference 2	REF 2		Non-BMP, non -manure monitoring site.
			Irrigated field sites
Battersea Drain Field	BDF	N,S	Nutrient management plan, stop applying manure, pivot modification and irrigation management to control runoff from irrigation.
Lower Little Bow Field	LLB	N,S	Nutrient management plan, stop applying manure, pivot modification and irrigation management to control runoff from irrigation, grass drainage channel.

[z] Beneficial management practices site abbreviations.

[y] C = cattle management BMPs involved infrastructure alterations, off -stream watering, windbreaks, fencing, bioengineering, and/or improved grazing plans; N = manure nutrient management BMPs on cropland involved nutrient management plans, application setbacks, and/or buffer zones; S = Surface -water management involved berming and redirecting the flow of surface water (FLT, CAT) or irrigation management to reduce runoff (BDF, LLB).

[x] While bioengineering projects were implemented, they were considered as reclamation projects rather than BMPs.

[w] Due to various factors, a BMP plan was not implemented at the SMF.

[v] Because of circumstances, the EFD site could not be used to evaluate BMPs. However, this site was used to assess the risk of liquid manure application onto a forage crop to runoff water quality.

Modelling Studies

To extrapolate the key research results obtained from the field research sites to other non-monitored fields within the study areas and to other parts of the province, the Comprehensive Economic and Environmental Optimization Tool (CEEOT) model was used (Figure 5). 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).

This framework was designed to evaluate the economic and environmental impacts of agricultural BMPs on water quality at field and watershed scales.

The key objectives of the CEEOT modelling component were to:

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

The CEEOT model was first applied to the IFC and WHC watersheds, as well as the LLB field site. It was then applied to a central portion of the Red Deer River (RDR) Watershed in central Alberta (Figure 6). A number of BMP scenarios were assessed using the model and compared to a baseline scenario (Table 2).

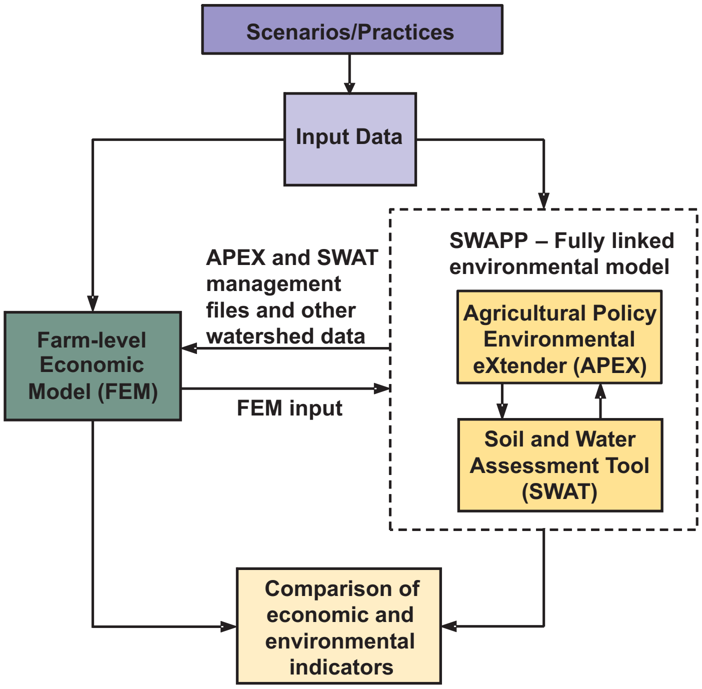


Figure 5. Schematic of the CEEOT model.

The selected RDR study area was approximately 1.2 million ha in size and represented about 25% of the entire Red Deer River Watershed (Figure 6). The RDR study area was chosen for its diversity. It has a relatively high agricultural intensity, and represents a variety of hydrologic conditions typical of five natural regions of Alberta: Rocky Mountains; Foothills, Boreal Forest; Parkland; and Grassland. Most of the RDR study area was located in the Central Parkland Natural Sub-region. The RDR study area was also selected because long-term water quality information existed for five sub-basins that were monitored as part of the AESA Water Quality Program from 1999 to 2006. These five AESA sub-basins ranged in size from 4,523 to 35,394 ha, and represented nearly 7% of the RDR study area. Additional information was available from Enivronment and Sustainable Resource Development's long-term water quality monitoring sites located along the Red Deer River within the study area.

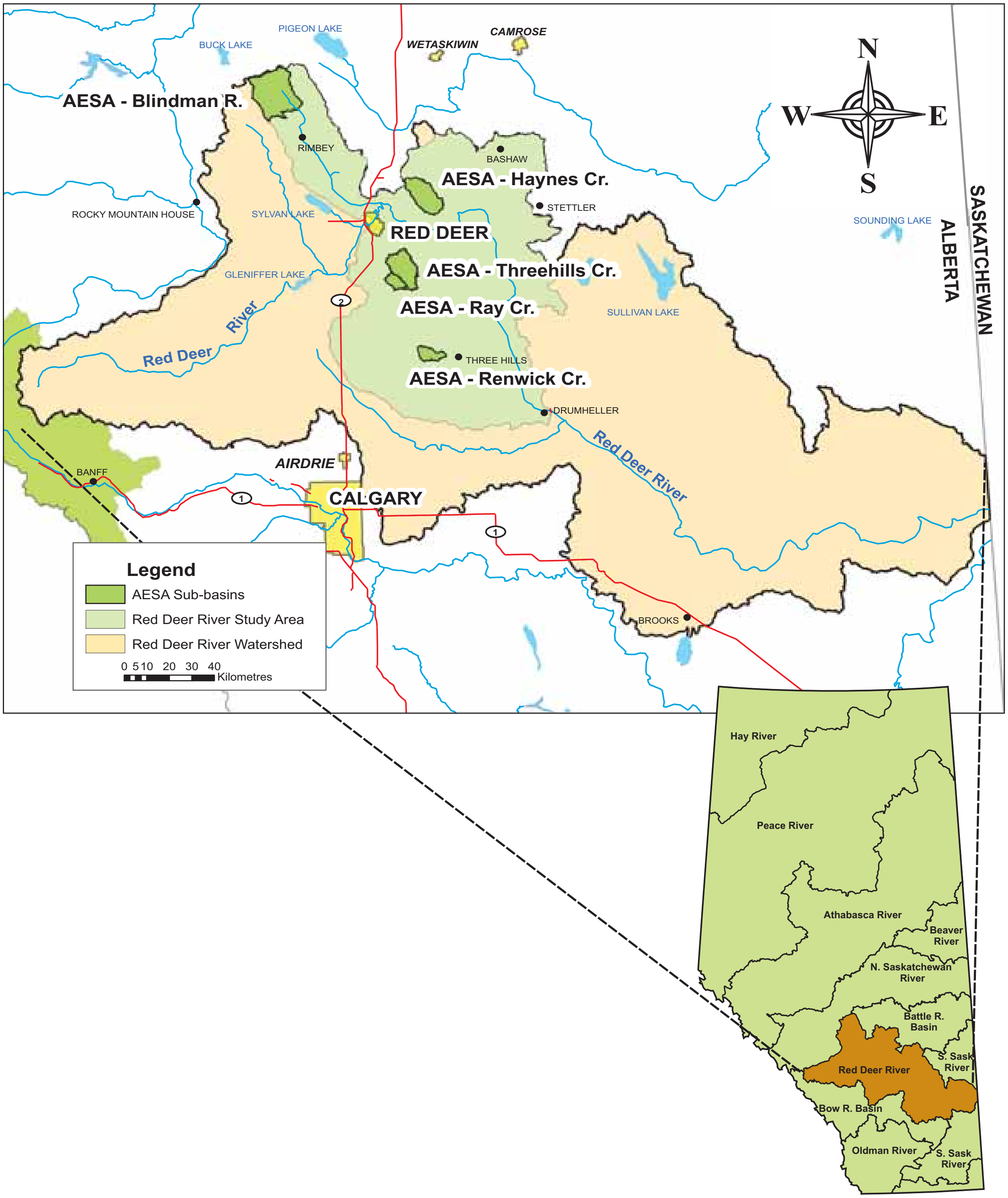


Figure 6. Location of Red Deer River study area in the Red Deer River Watershed.

Table 2. Scenarios simulated in the CEEOT model for the Indianfarm Creek Watershed, Whelp Creek Sub-watershed, Lower Little Bow site, and the Red Deer River area.

Watershed	Scenario	Manure BMPs							Cow-calf and riparian BMPs						
		Field study BMPs	Manure incorporation within 48 h	Manure AOPA setbacks	No application on snow	Soil nitrate nitrogen limits	Soil phosphorus limits	No manure applied in fall	Cattle restriction from creeks	Rotational grazing	15-m buffer strips	15-m grassed waterways	Wetland restoration	Reduced tillage in fall	Irrigation efficiency
Indianfarm Creek	1 (Baseline)														
	2 (Field Study BMPs)	X													
	3 (AOPA)[z]		X	X	X	X									
	4 (Cow-calf)		X	X	X	X			X	X	X	X			
	5 (P limit)		X	X	X		X	X	X	X	X	X			
Whelp Creek	1 (Baseline)														
	2 (Field Study BMPs)	X													
	3 (AOPA)		X	X	X	X									
	4 (P limit)		X	X	X		X	X							
	5 (Riparian)		X	X	X		X	X			X	X	X	X	
Lower Little Bow Field	1 (Baseline)														
	2 (Field Study BMPs)	X													
	3 (AOPA)		X	X	X	X									
	4 (P limit)		X	X	X		X					X			
	5 (Irrigation)		X	X	X		X					X			X
Red Deer River study area	1 (Baseline)														
	2 (Manure P management)					X[y]	X								
	3 (Rotational grazing)								X	X					
	4 (Seasonal bedding)								X[x]						
	5 (Grassed waterways)											X			
	6 (Riparian setbacks)										X				
	7 (Wetland restoration)												X		

[z] Agricultural Operation Practices Act.
[y] Crop removal rate of nitrogen.
[x] Cattle excluded from riparian areas in winter and a minimum of 100 -m setbacks from waterways.

Conclusions and Recommendations

Based on the field and modelling results the following conclusions and recommendations were developed.

Conclusions

Field Study

1. **Development of a watershed approach to BMP implementation required the collective support of area residents and ongoing communication to share concerns and develop solutions – it took time and trust building.**
   - Significant time and effort was required for the watershed groups and the BMP Project Team to build a relationship of trust before moving forward with development of environmental mitigation options.
   - Establishment of watershed groups in IFC and WHC were helpful as forums for education, awareness, and action. Concerns from watershed residents tended to align well with water quality issues.
   - The IFC Watershed Group was generally more interested and active than the WHC Sub-watershed Group. This may have been related to the visibility of environmental concerns in the IFC Watershed compared to the Whelp Creek Sub-watershed.
   - The IFC Watershed Group took leadership to apply for BMP funding, and a number of producers in the IFC Watershed, that were not originally part of the research project, requested support from the BMP Project Team to implement BMPs on their land.

2. **The mitigation of environmental water quality concerns required the implementation of site-specific suites of BMPs.**
   - On each farm, environmental concerns were identified and then a suite of BMPs was implemented to address the concerns.
   - Whole farm management should be considered in the design of BMPs to ensure that the problem is not moved elsewhere. For example, if soil nutrient levels are high and manure needs to be applied elsewhere, then the alternative location should have soils that require nutrients.
   - The BMPs needed to be site-specific and comprehensive, taking into account regional precipitation and surface runoff information.
     - Producer cooperation and participation were essential to ensure the BMP design was practical to implement and maintain.

3. **The addition of manure to the land by mechanical application will increase total nitrogen (TN) and total phosphorus (TP) concentrations in runoff water compared to non-manured or pasture sites.**
   - For pasture and non-manured sites, the average TN and TP concentrations in runoff water ranged from about 2 to 6 mg L^{-1} and from about 0.8 to 1.0 mg L^{-1}, respectively. These values reflected farm management on native grass, pasture land, and cultivated fields, which received only inorganic fertilizer.
   - Sites with moderate or heavy manure application (pre-BMP) had average TN

and TP concentrations in runoff water that ranged from about 12 to 14 mg L^{-1} and from about 2 to 5 mg L^{-1}, respectively.

- Fall grazing also increased TN and TP concentrations in runoff where cattle affected drainage channels in fields.

4. **Almost all of the BMP suites implemented at each site were effective at significantly improving water quality for TN, TP, total suspended solids (TSS), and/or *Escherichia coli* (*E. coli)* concentrations at the edge-of-field or immediately downstream.**
   - Beneficial management practises were implemented at 16 sites, and water quality data were used to evaluate BMP effectiveness for 11 of the sites.
   - Cattle management BMPs were most likely to show immediate or short-term water quality improvement; whereas, field nutrient management BMPs improvements required a longer term.
   - While a monitoring time frame of a few years may be sufficient to assess environmental benefits for some BMPs, more time may be required for other BMPs, depending, in part, on weather variability.
   - Of the six BMP sites that involved cattle management, four were effective at improving water quality. For those sites that did not have significant improvements, one site was trending towards improvement and any positive results at the other site were likely masked by the size of the upstream contributing area.
   - Of the five field-nutrient management BMP sites, four were effective at improving water quality. The site that did not show significant improvement had poorly implemented BMPs.
   - For the BMPs that were effective at improving water quality, average edge-of-field concentration reductions during runoff events were about:
     - 37% for TN;
     - 39% for TP;
     - 65% for TSS; and
     - 61% for *E. coli*.
   - However, post-BMP concentrations at the edge-of-field remained relatively high, and the relatively few BMPs implemented in each of the two project watersheds did not measurably improve water quality at the outlets.

5. **The location or scale of water quality measurement is important when evaluating the efficacy of BMPs as well as adherence to water quality guidelines or objectives.**
   - Generally, the smaller the scale (or the smaller Strahler stream order), the higher the concentration of nutrients expected.
   - Water quality concentrations are often used to assess BMPs. Measuring water quality at a smaller scale, like edge-of-field rather than in-stream, improves the likelihood of measuring a successful environmental response caused by BMPs.
   - Pre-BMP average edge-of-field concentrations typically ranged from 2 to 24 mg L^{-1} for TN, and 0.5 to 9 mg L^{-1} for TP. In comparison, the overall averages at the outlets of IFC and WHC were 2.2 to 3.0 mg L^{-1} for TN and 0.3 to 0.6 mg L^{-1} for TP.

6. **The costs of BMPs varied, but generally, BMPs for extensive livestock were less costly than BMPs associated with intensive livestock.**
   - The median cost of BMPs was about $12,000 per site among 17 sites.
   - Cost of implementing the BMPs ranged from $466 to $87,770, and labour ranged from 13 to 202 hours. Usually, most of the cost was a one-time, upfront cost.
   - The most costly BMPs involved:
     - Hauling manure an extra distance because of high soil-test phosphorus (STP) concentrations; and
     - Surface-water management to divert water around livestock pens.
   - Some costs, like manure hauling, may be incurred for the long-term (decades).

7. **Phosphorus reduction will require decades of mitigation efforts in fields with a long-term accumulation of soil P from manure application, and will be costly to implement.**
   - Agricultural fields within areas where there is a high intensity of confined feeding operations are at risk for soil nutrient accumulation due to excessive manure application.
   - These at-risk areas constitute a very small part of Alberta's agricultural land.
   - High soil nutrient concentrations are an environmental concern if there is a high potential for runoff caused by snowmelt, rainfall, and/or irrigation, resulting in a greater risk for surface water contamination and, if present, shallow groundwater contamination.
   - While transport of manure off-site is considered the most appropriate BMP, it is unlikely that producers will voluntarily implement this practice without long-term funding support.

8. **For irrigated fields with high soil nutrient concentrations from manure applications, BMPs that deal with the source and transport of nutrients are required.**
   - Theoretically, precision water application technology for irrigation pivot systems allows the producer to more efficiently and accurately balance water application with plant requirements. In practicality, there were implementation challenges with the variable rate technology used in this study.
   - Automatically turning off individual sprinkler nozzles or entire pivot spans significantly reduced irrigation runoff from contributing drainage areas of the irrigated fields.

9. **The BMP Project watersheds were representative of the Grassland and Parkland natural regions, and the results should inform future BMP approaches and recommendations throughout much of Alberta's agricultural regions.**
   - For the Grassland Natural Region watersheds, BMPs that target particulate concentrations during the spring rains would be most effective. These include BMPs related to cow-calf, riparian, and field erosion management.
   - For the Parkland Natural Region watersheds, BMPs that target dissolved inorganic nutrient concentrations in snowmelt would be most effective. These include BMPs related to intensive livestock manure management.

10. **As expected, the relatively few BMPs implemented in each of the project watersheds did not measurably improve water quality at the outlet.**
    - Water quality improvement at the watershed outlet will likely require implementation of a greater number of BMPs within the critical source areas of the watershed.
    - The majority of BMPs that were implemented were targeted for concentration reductions in water, and did not reduce off-farm flows. Similar to other Alberta-based studies, this study confirmed that flow was the primary driver for the observed load and export differences at the watershed outlets. Hence, BMPs may reduce concentrations, but are unlikely to have a large effect on loads and exports.

11. **Shallow groundwater conditions must be considered in the design and assessment of BMPs.**
    - At two of six sites where groundwater was monitored in WHC, it appeared that nitrate-nitrogen (NO_3-N) and chloride (Cl) leached in the soil profile to a depth of 1.5 to 2 m and was likely related to manure application.
    - The implemented field BMPs did not target groundwater and no change in groundwater quality related to the BMPs was observed in WHC.
    - Shallow groundwater NO_3-N and Cl concentrations in the WHC Sub-watershed were generally less than Canadian Drinking Water Quality Guidelines.
    - There was no relationship between flow and the concentration of surface water quality parameters in WHC (unlike IFC). This may have been related to the groundwater contributions to the surface flow, which was estimated at 48% of the total annual flow at the sub-watershed outlet.
    - Most of the groundwater quality was better than the surface water quality. When groundwater discharged to the surface flow it likely diluted the nutrient concentrations at the WHC outlet.

<u>Modelling Study</u>

12. **The CEEOT model was able to simulate the environmental and economic impacts of suites or scenarios of BMPs at the farm and watershed scales.**
    - In addition to the benefits of estimating the economic and environmental implications of alternative BMP scenarios, the CEEOT model application to the BMP Project watersheds can be utilized for future applications in other watersheds in Alberta.
    - The model can provide planners and agricultural producers the ability to prioritize BMP implementation strategies on the basis of environmental effectiveness as well as overall cost-effectiveness.
    - Policy makers can use information from the model to determine where support programs may be most effective in achieving water quality objectives within different agricultural regions.

13. **The Farm-level Economic Model, which assessed the annual economic impact of BMPs on farm profits for 30 to 35 years, showed that financial impacts were greater in some years than others.**
    - Most of the BMP scenarios involved construction and/or capital purchases that were incurred at the start of the scenario.
    - Other costs, such as the loss of crop production, were incurred annually for the entire modelling period.
    - Although annual impacts may be small, the long-term cumulative impacts on farm profits may be significant.

14. **The model BMP scenario performance was validated as it confirmed several conclusions from the field study.**
    - Scenario 2 (Field Study BMPs) did not result in large water quality improvements at the watershed outlets when compared to the baseline.
        - This reflected the few BMPs that were implemented relative to the land base in the watersheds.
        - In contrast, significant edge-of-field water quality improvements were predicted by the implementation of BMPs.
    - Scenario 3 (Agricultural Operation Practices Act, AOPA, with manure management based on NO_3-N limit) was only slightly more effective at improving water quality than Scenario 2.
        - The baseline scenario and Scenario 2 were similar to Scenario 3, except for the inclusion of manure application setbacks in Scenario 3.
        - The environmental and, to a lesser extent, the economic impacts of Scenario 3 were dependent on the distribution of manure application fields and common bodies of water, i.e., the more manure fields were closer to water bodies, the greater the impacts. This was illustrated as Scenario 3 resulted in greater water quality improvements in WHC than in IFC and LLB, because WHC had greater numbers of manured fields and common water bodies.

15. **Although the model simulated that riparian and cow-calf BMPs resulted in significant reductions of sediment and nutrient losses, the environmental outcome may not be significant, depending on the watershed.**
    - In WHC, the riparian BMPs resulted in about 50% reduction of TSS, TN, and TP loads compared to the baseline scenario.
    - In IFC, the cow-calf and riparian BMPs resulted in about 25% reduction of TSS loads and about 60 and 50% reduction of TN and TP loads, respectively, compared to the baseline scenario.
    - Although the reductions appear substantial in both watersheds, WHC generally had very low baseline TSS and particulate nutrient concentrations, so the reduction may not be biologically significant. In contrast, IFC TSS and particulate nutrient concentrations were relatively high, and reduction in these parameters may be environmentally beneficial.
    - The economic impacts of these BMPs were minimal in areas where prime cropland was not involved, because the opportunity cost of the land placed in these structural controls was relatively low compared to higher valued cropland.

16. **All BMP Project watershed model scenarios resulted in negative net returns either from a decline in revenues or an increase in cost.**
    - The economic impact of BMPs varied among farms and depended on the individual farm characteristics and the extent to which the BMP was applied.
        - The size of the individual representative farms affected the magnitude of the economic impact.
        - Large farms had smaller economic impacts per hectare than small farms.
    - Some scenarios will reduce loads for a given indicator much more cost-effectively than for others.

17. **For the Red Deer River study area, most BMP scenarios were successful at reducing nutrient losses from the farm or the study area as a whole, and usually at a financial cost to the producer.**
    - Of the six BMP scenarios, only two provided a win-win outcome, i.e., a reduction in nutrient loss and an increase in farm profit.
        - Scenario 3 (rotational grazing) was the only BMP scenario shown to be clearly cost-effective in terms of moderate environmental improvement, and increases in farm profits. At the RDR study area scale, the profit increase was about \$4 ha^{-1} yr^{-1}, which amounted to about \$3 million per year in additional farm profits at the study area scale.
        - Scenario 2 (manure management) resulted in slightly improved farm profits but provided more than twice the reduction in TP load than Scenario 3.
        - The cost was minimal for Scenario 4 (seasonal bedding and feeding sites) and the environmental improvements were modest.
        - Scenarios 5 and 7 (grassed waterways and wetland restoration, respectively) 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 implemented throughout the watershed where applicable, the overall costs to the region amounted to almost \$4 million per year.

18. **Water quality improvements were more easily demonstrated at the edge-of-field or at the outlet of relatively small watersheds than for a larger watershed like the Red Deer River study area.**
    - The impacts of the mountain-fed base flow in the Red Deer River often overshadowed the cumulative effects of BMP scenarios in the RDR study area.
    - These modelling results were validated and supported by findings from the BMP Field Study, i.e., scale makes a difference when considering measurable changes in sediment and nutrient concentrations.

19. The most environmentally effective BMPs varied among the study areas and this highlights the need for several BMP options in order to address the diversity of Alberta's landscape and agriculture.

- In IFC Watershed, Scenario 4 (cow-calf and riparian BMPs) resulted in the largest environmental gains and was also the most cost-effective scenario when compared to the other IFC scenarios (Table 3).
- The buffer strips, grassed waterways, and wetland restoration in Scenario 5 showed the greatest environmental improvements in WHC Sub-watershed (Table 3), albeit at a significant cost.
- At the LLB site, Scenarios 4 (P limit) plus 5 (irrigation management) showed an improvement in water quality. However, as found in the field study, the modelling showed there will be a significant cost to haul excess manure off-site.
- In the RDR study area, Scenario 2 (P limit) resulted in the largest overall reduction in P, with a small profit (Table 3). However, the most effective environmental scenario varied among the AESA sub-basins. Scenario 6 (riparian setbacks) was effective at reduction TN, TP, and TSS, but with the largest reduction in farm profit in the study area.

20. The model predicted that P-based manure application limits were more effective in reducing TP at the edge-of-field than at the watershed outlets.

- In the IFC Watershed and WHC Sub-watershed simulations, agronomic P-based manure application resulted in TP reductions of about 1% at the watershed outlets (Table 4).
  - This small reduction may be related to the relatively few fields that receive manure in IFC and the fact that most soils were below agronomic P concentrations in both watersheds.
- In contrast, TP reduction at the edge-of-field (LLB site) was more than 50% when manure application was based on agronomic P rate compared to the baseline scenario, for which manure was applied based on the AOPA NO_3-N rate.
  - The LLB site had STP concentrations that were very high (>200 mg kg^{-1}).

Table 3. The most effective environmental scenarios from the CEEOT model.

Watershed[z]	Scenario	Farm Profit ($ ha^{-1} yr^{-1})	Change in TN from baseline (%)	Change in TP from baseline (%)	Change in sediment (%)
IFC	4 (Cow-calf + riparian)	-2	-61	-48	-25
WHC	5 (Soil P limits + riparian)	-76	-52	-56	-45
LLB	5 (Soil P limits + irrigation)	-45	-85	-56	-11
RDR	2 (Soil P limits)	0.42	-4	-28	0.2
AESA 1	3 (Rotational grazing + riparian)	11	-11	-13	-8
AESA 13	3 (Rotational grazing + riparian)	1.31	-25	-10	-9
AESA 24	2 (Soil P limits)	1.34	-23	7	-64

[z] AESA 1 = Blindman River, AESA 13 = Haynes Creek, AESA 24 = Ray Creek.

Table 4. The model simulated effects of beneficial management practices scenarios on total phosphorus (TP) for Indianfarm Creek Watershed, Whelp Creek Sub-watershed, and Lower Little Bow Field.

Indianfarm Creek Watershed		Whelp Creek Sub-watershed		Lower Little Bow Field	
Scenario[z]	TP reduction from baseline (%)	Scenario[z]	TP reduction from baseline (%)	Scenario[z]	TP reduction from baseline (%)
2 (Field study)	-1.2	2 (Field study)	-6.6	2 (Field study)	-56
3 (AOPA)	-0.7	3 (AOPA)	-15	3 (AOPA)	-6
4 (Cow-calf)	-48	4 (P limits)	-16	4 (P limits)	-55
5 (P limits)	-49	5 (Riparian)	-56	5 (Irrigation)	-56

[z] Scenarios 3, 4, and 5 are cumulative, i.e., the percent change for Scenario 4 includes the contribution from Scenario 3, and the percent change for Scenario 5 includes the contributions from Scenarios 3 and 4.

21. Four of the most environmentally effective scenarios modelled in the Red Deer River study area included P-based manure management, with varied impacts on farm economics.

- For watersheds that have relatively small livestock operations and low animal densities, P-based manure management may result in overall cost-savings to the livestock operations. These farms are more likely able to apply the manure on-farm, resulting in fertilizer cost savings that can offset the increased cost of manure nutrient applications.
- For watersheds having larger livestock operations with higher animal unit densities, P-based manure nutrient management BMPs resulted in higher costs, primarily because of additional hauling distances and manure spreading costs, which offset any fertilizer cost savings.

22. Implementing P-based manure management in the Red Deer River study area would require increased manure hauling as more manure would need to be transported from a greater number of farms.

- The RDR study area included 4802 farms (about 3000 crop; 1500 cattle; 200 swine; and 55 dairy).
- The baseline scenario showed slightly more than 500 farms haul about 60% of their manure off-farm. The model results showed a higher percentage of liquid manure tended to be hauled off-farm than solid manure.
- The move to P-based manure management would require the 500 farms that haul manure to haul an additional 20% more manure (80% of their manure) off-farm. Additionally, about 760 farms that did not haul manure in the baseline scenario would have to haul on average 30% of their manure off-farm if P-based manure management occurred.

23. 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 had a higher potential for generating greater amounts of flow, sediment, and nutrients.

- 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 represented 20% of the RDR study area and contributed 65% to the total load of the environmental indicators.

Scientific Recommendations

1. **Develop specific water quality objectives for key nutrients such as TN and TP in agricultural watershed streams that reflect the naturally nutrient-rich prairie soils.**
   - Research is required to define background nutrient levels in the natural environment of Alberta's agricultural regions, and to develop practical, achievable, and acceptable nutrient concentration objectives in streams and tributaries.
   - Water quality objectives will help the agricultural industry and producers define success in their pursuit of environmental sustainability.

2. **A key preventative plan to protect water quality is to avoid the build-up of soil nutrients on agricultural land.**
   - Repetitive manure application through grazing or field application can quickly cause nutrients to accumulate in soil.
   - Hotspots, or small areas with high nutrients, can develop within fields if manure or livestock are confined to a small area.
   - High soil nutrient concentrations are an environmental concern if there is a high potential for runoff caused by snowmelt, rainfall, and/or irrigation.
   - The residual accumulation of organic P from manure will maintain STP concentrations for several years after manure application is stopped.
   - Regular soil testing should be practiced to monitor potential soil P accumulation.
   - Phosphorus-based management may be cost-effective for small livestock operations but it is not cost-effective for large operations that have less land per animal unit. Current funding programs do not support long-term BMP costs like hauling manure greater distances.

3. **Critical source areas should be mapped and defined for all agricultural watersheds in Alberta.**
   - Research continues to show that relatively small areas or sub-basins within watersheds often contribute the majority of nutrient loading to receiving streams and tributaries.
   - Accurately defining these areas will allow effective planning of new intensive livestock development, and focus water quality mitigaton efforts in areas that will be the most cost-effective.

4. **Suites of agricultural BMPs should be implemented within watersheds in order to achieve measurable downstream water quality improvement.**
   - This study showed that BMPs at individual sites are unlikely to be successful in significantly improving water quality in receiving streams and at the watershed outlet.

- A defined number of many BMP suites, properly designed and implemented at key watershed locations (i.e., critical-source areas), should successfully mitigate agriculture-related water quality issues at the watershed outlet.
- Programs that support the coordination of BMP assessment, design and implementation at the watershed scale should be encouraged.

5. **Alberta should continue to assess the cumulative and long-term effectiveness of BMPs to mitigate the impacts of agricultural management on water quality at the watershed scale.**
   - The BMP Project provides a good template to move forward with cooperation among producers, industry, and government. This has continued in the current 'Alberta Phosphorus Watershed Project (started in 2013)', which has the objectives to develop a P-loss risk management tool, implement a critical number of BMPs in critical-source areas, and assess BMP effects on water quality at the outlet of agricultural watersheds.
   - Results from watershed research programs should be demonstrated to agricultural producers through on-site tours, interviews with cooperating producers, publications, and the internet.

Irrigating canola

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Wetland and cropland