Nutrient Beneficial Management Practices Evaluation Project

Volume 1
Summary and Recommendations

Alberta
Government

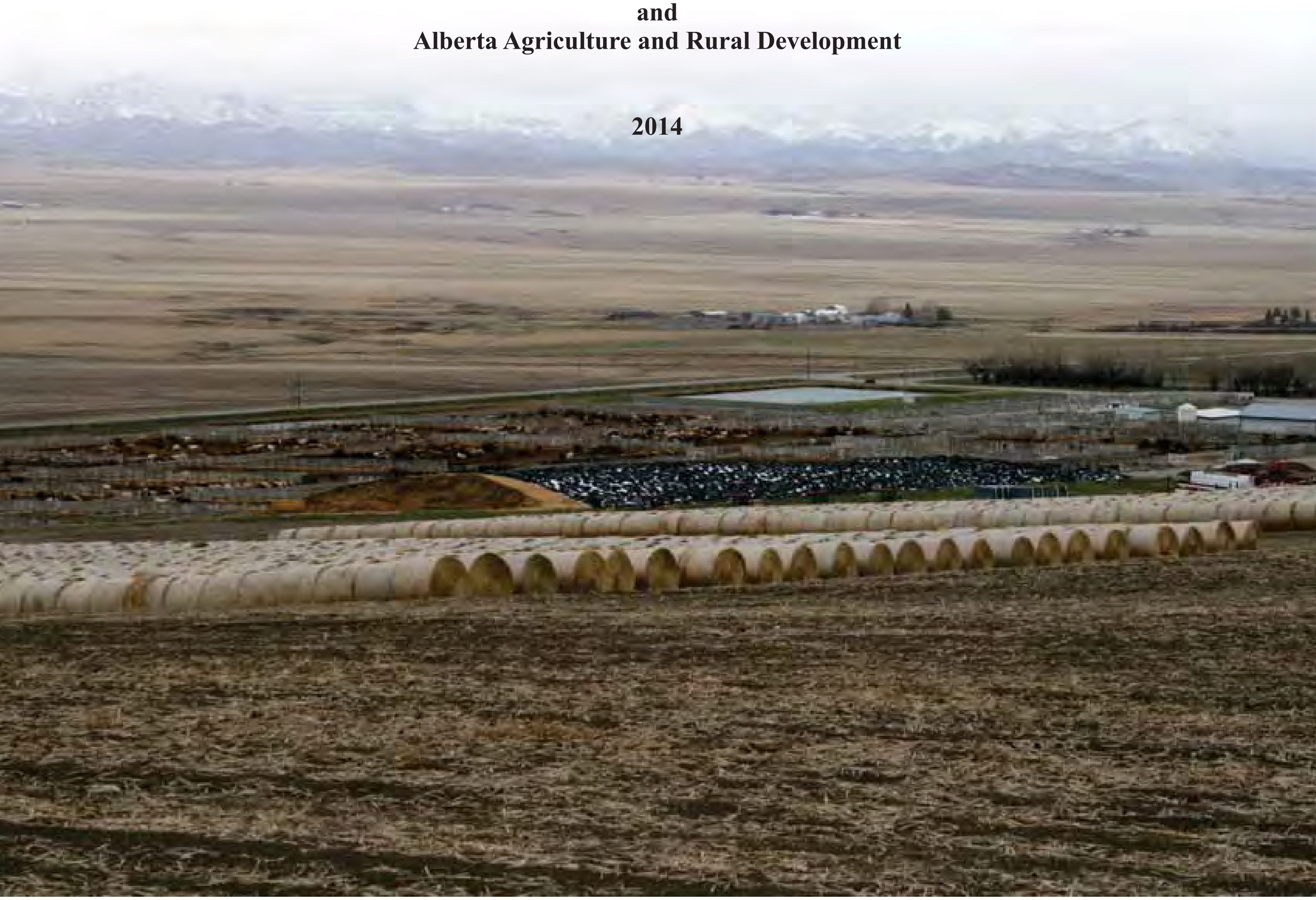
ACIDF
Alberta Crop Industry Development Fund Ltd.

Nutrient Beneficial Management Practices Evaluation Project

Volume 1:
Summary and Recommendations

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

2014



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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.

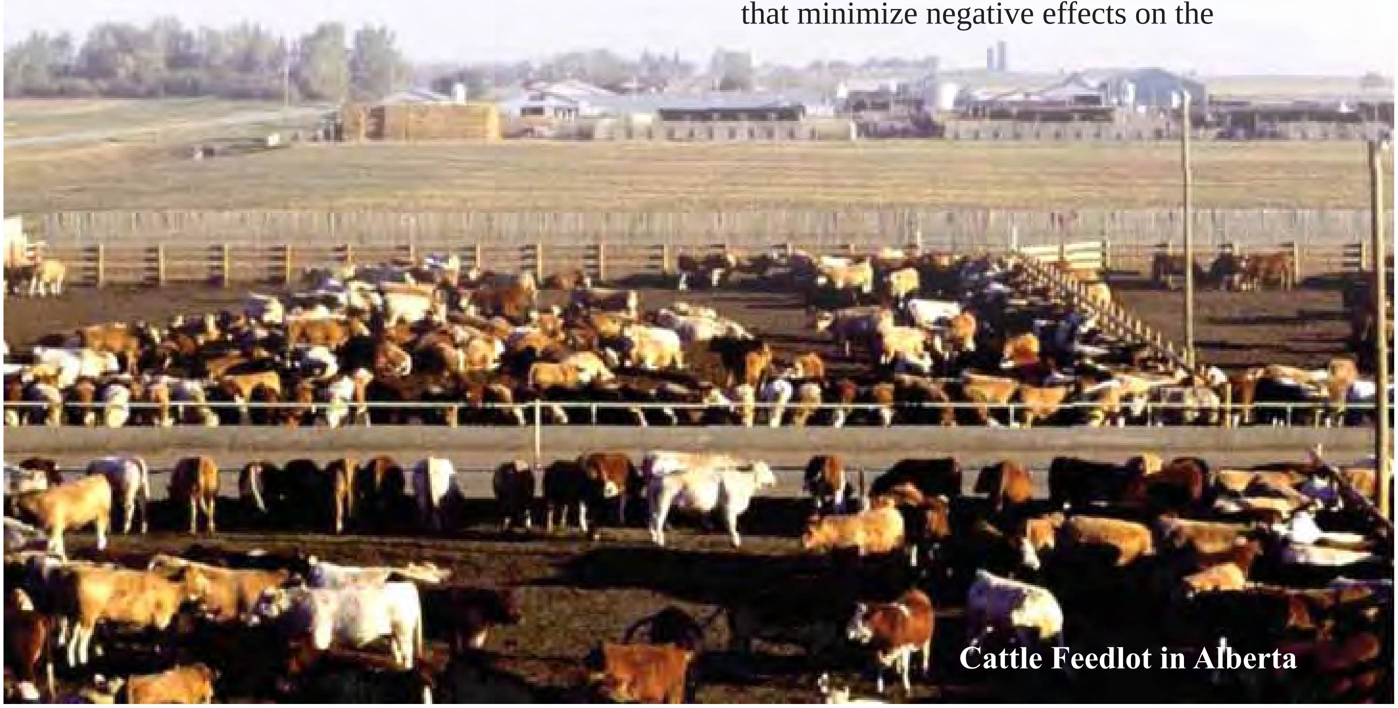
Alberta's crop and livestock producers face challenges every day with increasing input costs, market competition, and continued pressure to improve environmental stewardship. The risks to the environment from agriculture are many, with a major concern regarding impacts of agricultural management on water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

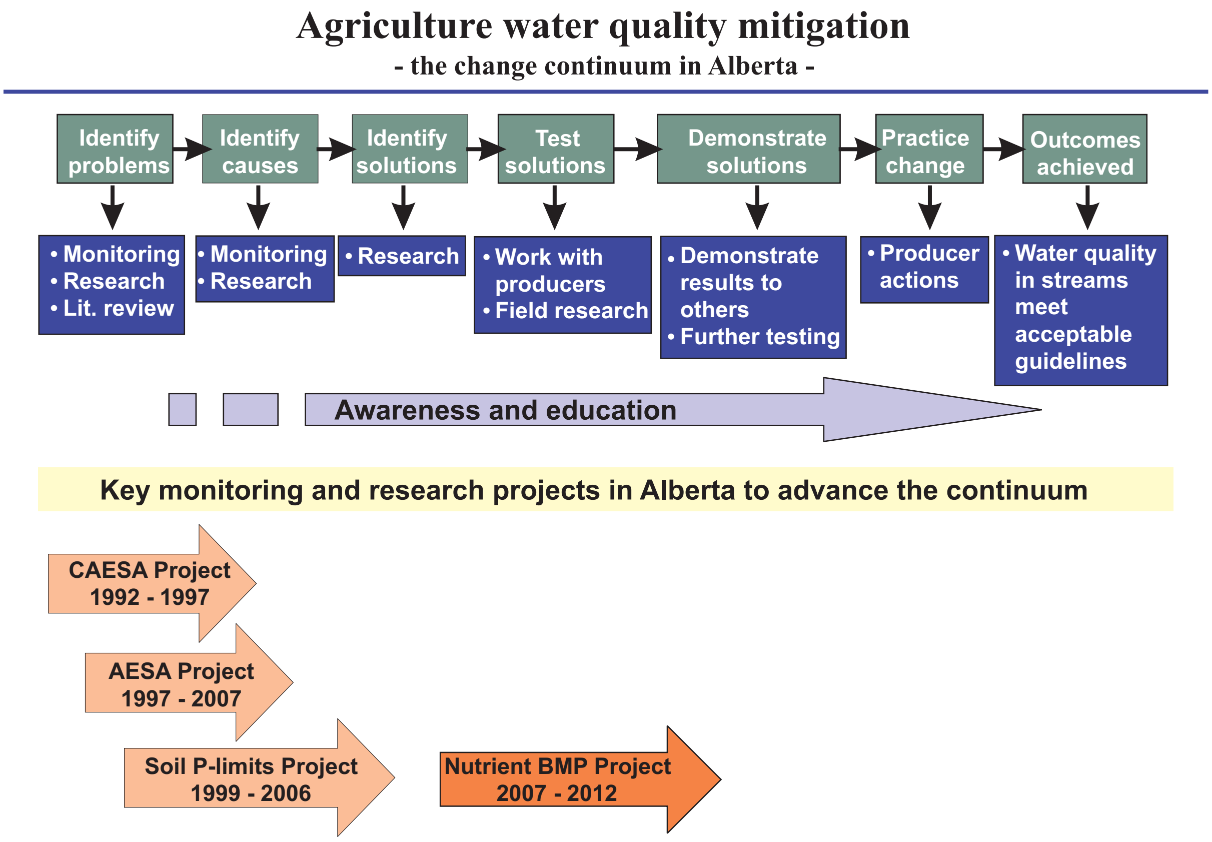


Figure 1. Schematic of agriculture water quality mitigation strategy for Alberta.

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

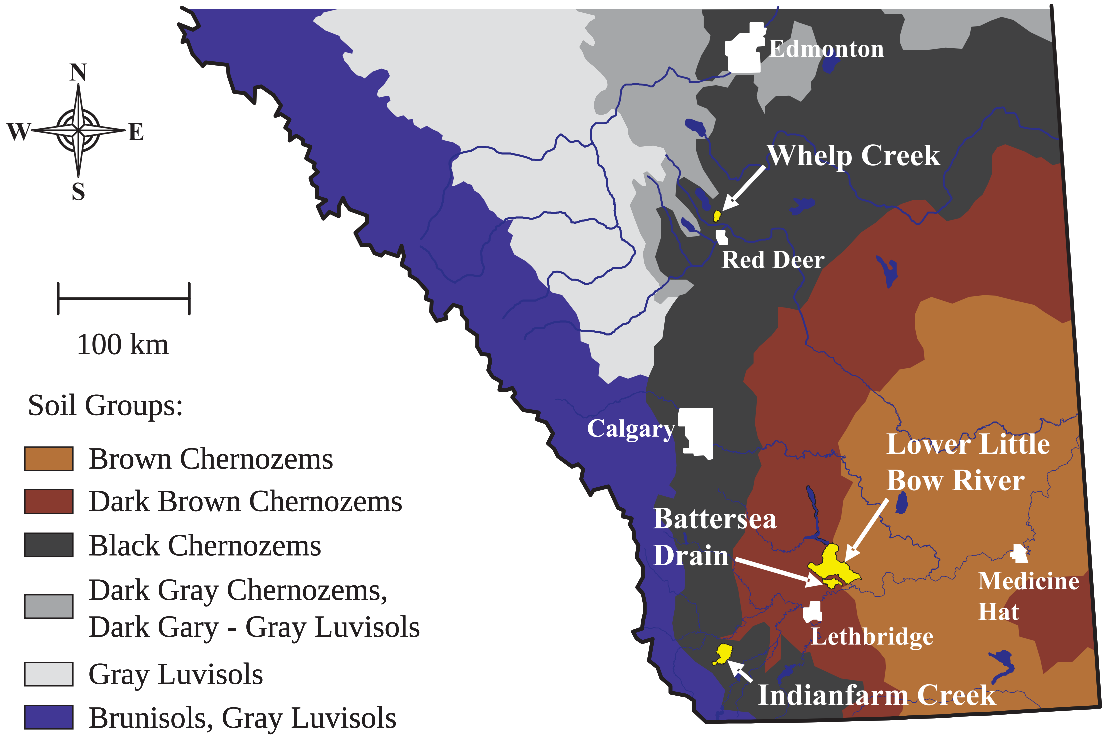


Figure 2. Location of the Nutrient Beneficial Management Practices Evaluaton Project research sites.

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.

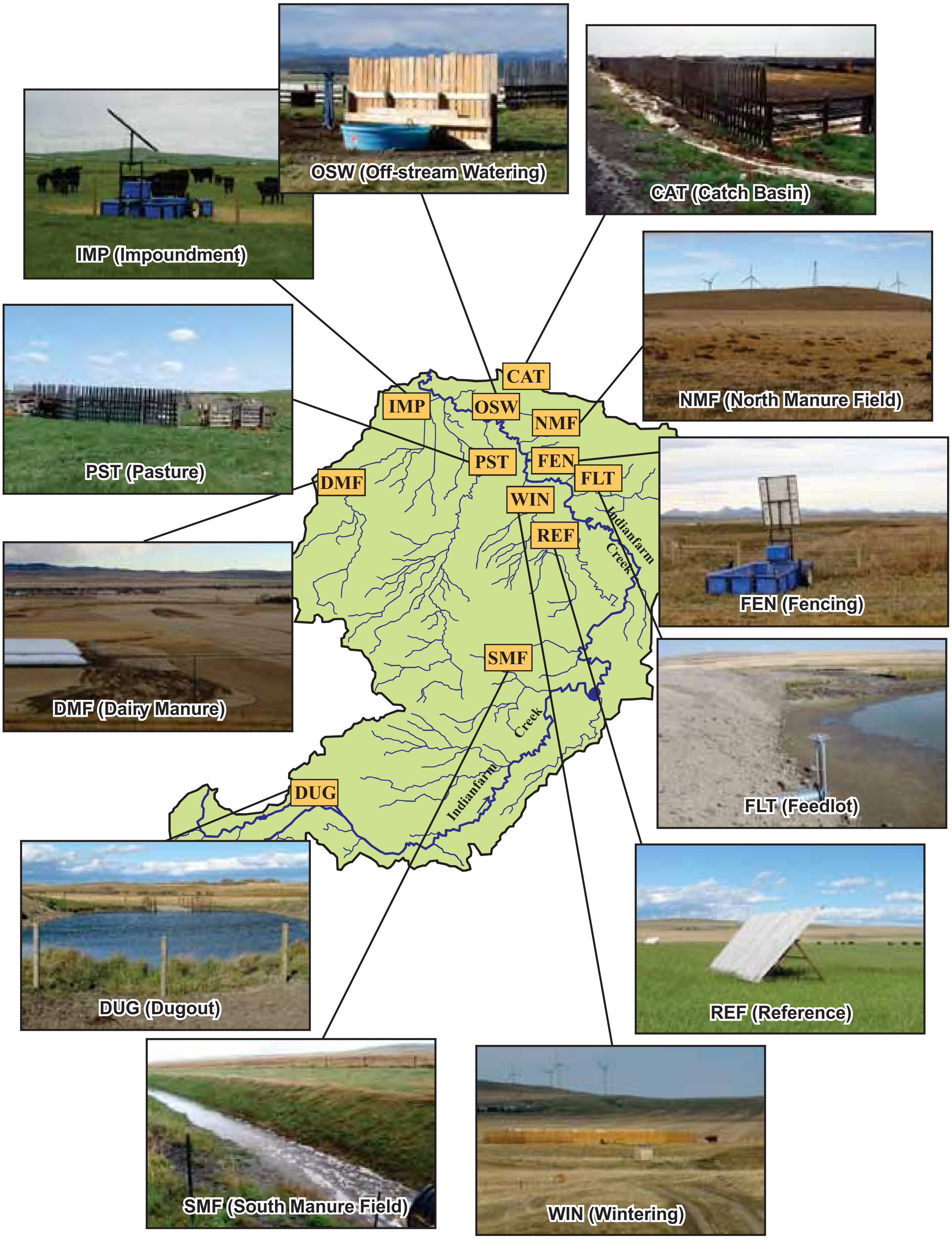


Figure 3. Overview of beneficial management practices sites in the Indianfarm Creek Watershed.

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).

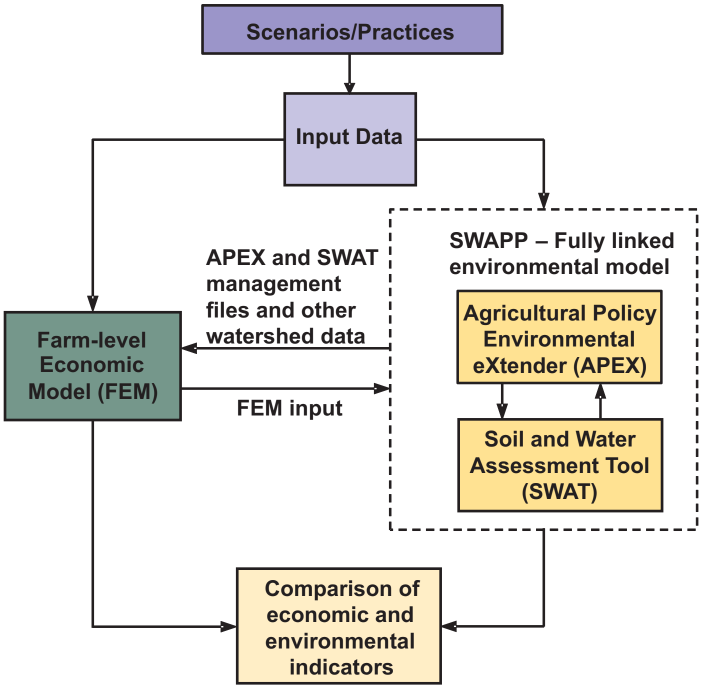


Figure 5. Schematic of the CEEOT model.

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.

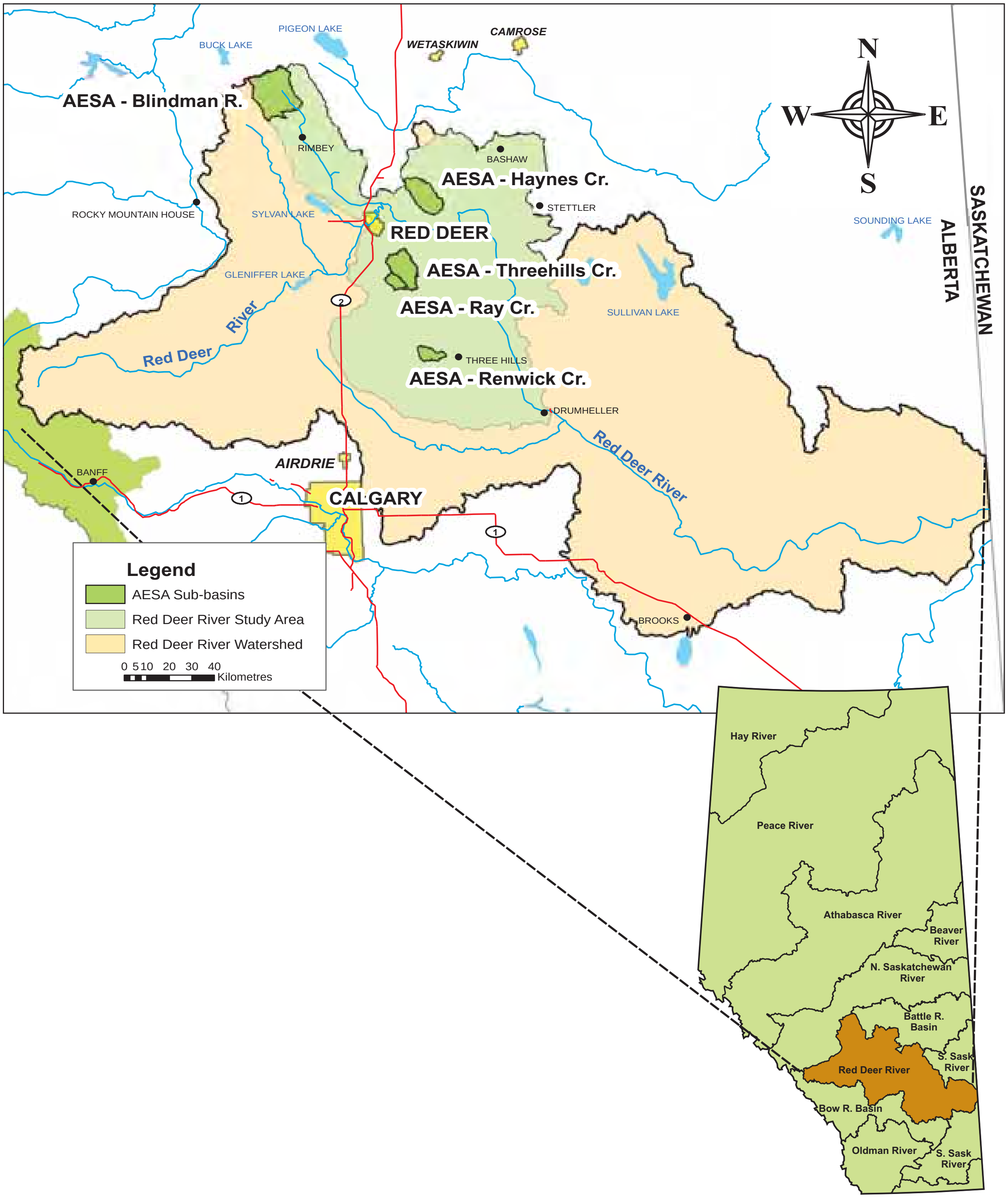


Figure 6. Location of Red Deer River study area in the Red Deer River Watershed.

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.

Modelling Study

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.

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1 INTRODUCTION

1.1 Agriculture in Alberta

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. Agriculture in Alberta generated almost $12 billion in total farm cash receipts in 2013 (ARD 2014a). About 230,000 Albertans are employed in the agriculture and food retail industries in Alberta. The total economic contribution of Alberta's rural economy is estimated to be approximately $79 billion annually (Conference Board of Canada 2013). Next to the energy sector, the agri-food industry is the most important driver of Alberta's economy.

Alberta is a leader in the production and processing of agricultural crops, livestock, and non-food agricultural products, and is one of a few regions in the world that will be a net exporter of agri-food products in the future. As global demand for safe and high-quality food and agricultural products continues to grow, Alberta is well positioned to further increase agricultural production and help meet the growing global markets.

Alberta's agricultural land base is about 21 million ha, which represents about 33% of the province's total land base. About 12 million ha of the agricultural land base is cultivated for crop and forage production. About 640,000 ha of the cultivated land base are irrigated, with the majority of that located in southern Alberta. This accounts for almost 70% of Canada's total irrigated land base.

The agricultural land base has remained relatively stable, but the number of farms continues to decrease. In 2011 there were 43,234 farms (ARD 2014a), which is down from 49,431 farms in 2007. Average farm size has increased from 427 ha in 2007 to 467 ha in 2011.

Farming has become a complex, highly specialized industry with national and international market connections. Farms are becoming larger and require much greater investment and risk. These larger farms are producing food not only for domestic markets, but for markets throughout the world. With the market for Alberta's agricultural products growing on a global scale, Alberta producers and processors now take a much more global view of marketing and competitiveness. The industry has seen great benefit from innovation to improve yields, increase competitiveness, and become more environmentally sustainable.

1.2 Agriculture and the Environment

Alberta's crop and livestock producers face challenges every day with increasing input costs, market competition, and continued pressure to improve environmental stewardship. Producers increasingly recognize that environmental stewardship is a quality of life issue and a potential economic marketing opportunity. However, before investing, they seek proven management practices that will maintain efficient and viable farm operations while protecting the environment.

The risks to the environment from agriculture are many, with a major concern regarding impacts of agricultural management on water quality. It is recognized that agricultural practices have the potential to impair surface water quality and the surrounding environment. Inversely, environmental events and poor surface water quality can negatively impact agricultural production (Council of Canadian Academies

2013). 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 (Figure 1.1). 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, and these can then enter ground or surface water (Smith et al. 2010).

Figure 1.1. Intensive cattle feedlot in Alberta.

Soil and water conservation practices have has been around since the late 1800s. Economic loss as a result of drought conditions and poor cropland practices of the infamous 1930s in Canada and the United States catalyzed governments to invest in and encourage conservation practices on private land. The push for scientific knowledge about soil and erosion prevention initiated the soil and water conservation movement (Johnson 1987). This paved the way for the advancement of technology and practices for what are today called beneficial management practices (BMPs).

Beneficial management practices defined as conservation practices, management techniques, or social actions that minimize negative effects on the environment while being practical tools for producers to meet or exceed legal requirements and production targets (AFRD 2004; Sharpley et al. 2006). Numerous BMPs have been developed and promoted to minimize the impacts of agriculture on the environment and increase the sustainability of the agricultural industry.

Beneficial management practices have been developed for the protection of water quality by managing nutrient inputs at the source and application methods. Examples include nutrient management plans; timing of manure application to avoid saturated, snow-covered, and frozen soils; injection of liquid manure; incorporation of surface applied manure; the maintenance of healthy riparian and pasture areas; and livestock management. Nutrient management fulfills crop nutrient requirements and minimizes the potential for nutrients to become diffuse sources of contaminants (Oenema and Pietrzak 2002).

The effectiveness of BMPs under Alberta conditions is not well known. This is, in part, because many BMPs were developed in other parts of North America or at a research plot scale. Individual BMPs have rarely been evaluated under Alberta field conditions (Wuite and Chanasyk 2003; AAFC 2007) and recent studies have recommended further research, especially with respect to phosphorus (P) management (Paterson et al. 2006). In addition, producers are requesting site-specific, risk-based analytical tools to assist them in deciding which management practices would yield the greatest impact for their financial investment. Science-based evidence is required to determine which practices reduce risks to producers, are environmentally effective, and can be practically implemented at a reasonable cost.

1.2.1 Surface Runoff

Climate, soils, field management, and landform all combine to influence surface runoff (Kleinman et al. 2006). Runoff is usually generated when rainfall intensity exceeds the infiltration capacity of the soil (Horton 1933, 1940) and when the water table rises to the soil surface such that the water storage capacity of the soil is exceeded, resulting in a saturated soil condition (Hursh 1944; Dunne 1970).

Not all areas of a watershed contribute runoff equally. Critical source areas produce more contaminants than surrounding areas, and occur where a pollutant source coincides with hydrologic transport mechanisms (Gburek and Sharpley 1998; Meals et al. 2012). Critical source areas can also occur as a result of a combination of characteristics that makes an area vulnerable to nutrient loss such as soil type, land use, slope, and proximity to streams and other water bodies (White et al. 2009). This results in the potential for a small portion of the watershed to contribute the majority of exported material. Critical source areas typically vary with event. A one-in-five year precipitation event may have a smaller critical source area than a one-in-one hundred year precipitation event because hydrologic connectivity and subsequently transport potential are increased with greater precipitation. Gburek and Sharpley (1998) suggest that P export be managed by focusing on control of P levels in hydrologically active zones that are most likely to produce surface runoff.

Studies on several agricultural watersheds in Alberta have shown that the total yearly surface runoff from small agricultural watersheds is dominated by snowmelt (Gill et al. 1998; Wuite and Chanasyk 2003; Ontkean et al. 2005). A three-year study of eight, field-scale (92 to 248 ha) watersheds in Alberta demonstrated that spring runoff (primarily snowmelt) and summer runoff (primarily rainfall) varied geographically within Alberta (Little et al. 2006). This study demonstrated that an average of 91% of the total runoff volume was from summer runoff (rainfall plus irrigation) at a small watershed in southern Alberta. A site near Grande Prairie in northern Alberta had 71% of total runoff occur as summer runoff. In contrast, three sites in central Alberta had about 82% of the total average runoff volume was spring snowmelt runoff. In spite of some regional differences, Little et al. (2006) found that on average about 90% of the runoff came from spring snowmelt among the eight sites.

Nutrient concentration in the soil, such as P, can be linked with runoff potential to provide an indication of surface runoff concentrations. Jedrych et al. (2006) developed a method to calculate site-specific, soil-test phosphorus (STP) limits for agricultural land in Alberta and tested the method on six watersheds and seven micro-watersheds in Alberta. They found that STP variance was related to runoff potential among soil polygons within each watershed and micro-watershed.

Stream flow and runoff volumes vary throughout Canada depending on physiographic and climatic patterns (Cole 2013). At the larger scale, runoff is often measured by the Annual Unit Runoff, which is a measure of runoff volume per square kilometre. This has been calculated for much of Canada to understand runoff patterns (Cole 2013). These values have also been used to determine on-farm water storage structure design and determining water availability for project licensing. The annual unit runoff for Canada is also an indicator for runoff potential and thus contaminant transport. According to the

Annual Unit Runoff Report, expected runoff volumes on average in southern Alberta can range from 2 to 600 dam^3 km^{-2} (Cole 2013). The report predicts higher values in Alberta's boreal forest, foothill and mountain regions, and low values in the plains and prairie regions (Cole 2013).

1.2.2 Nutrients

Eutrophication is the over-enrichment of surface water with nutrients, resulting in excessive production of algae and other aquatic vegetation (National Academy of Sciences 1993; Daniel et al. 1994; Correll 1998) (Figure 1.2). Eutrophication is a natural process but it can be accelerated by anthropogenic activities. Excessive production of algae and aquatic vegetation is accompanied by high respiration rates when the plants decay, leading to hypoxia or anoxia in lakes and streams, and the release of materials normally bound to bottom sediments including various forms of P (Kim et al. 2003; Ajmone-Marsan et al. 2006). Eutrophication is frequently associated with fish kills; loss of biodiversity; loss of aquatic plant beds and coral reefs; overall degradation of aquatic ecosystems; and the impairment of water quality for drinking, recreation, irrigation, and other purposes (Carpenter et al. 1998).

Figure 1.2. Eutrophication in water.

The combination of increased levels of dissolved inorganic nitrogen (DIN) and P (DIP), the ratio of DIN:DIP, and the influence of climatic factors such as light and temperature, have been associated with the eutrophication of surface waters (Isermann 1990). In freshwaters, P is the main limiting nutrient and N is the second limiting nutrient, while in coastal waters the reverse is true (Schindler 1977; Cullen and Forsberg 1988; Isermann 1990; Blomqvist et al. 2004). Thus, most freshwater studies focus on the control of P to minimize accelerated eutrophication of fresh water systems (Schindler 1974; Sharpley et al. 1987).

Nutrients, such as total N (TN) and total P (TP), can be divided into dissolved and particulate forms, and each form can be further subdivided into inorganic and organic fractions (Gburek et al. 2005). Dissolved reactive P (DRP) is the fraction of P that reacts with molybdate during the Murphy-Riley analytical procedure (Murphy and Riley 1962) and this fraction consists of orthophosphate ($H_2PO_4^-$ or HPO_4^{2-}) and other inorganic P forms and some organic P (Gburek et al. 2005). The principal forms of N exported through runoff are ammonia (NH_3), ammonium ion (NH_4^+), and nitrate (NO_3^-) (Marston 1989). Ammonium is easily transformed to NO_3^-. Phosphorus and NH_4^+ are relatively immobile in the soil, while NO_3^- is quite mobile and can easily leach into groundwater (Chang and Entz 1996). Nitrogen and P as surface water contaminants often originate on land and are transported to surface water through overland routes through runoff and erosion, and subsurface routes such as groundwater leaching and flow (Nash and Halliwell 2000; Haygarth et al. 2005).

Commonly, nutrients are lost or transported by attaching to eroded sediment in surface runoff (Figure 1.3), dissolved in surface-

Figure 1.3. Field erosion during spring snowmelt.

runoff water, or dissolved in leaching water (Baker et al. 2008). Soil erosion by water can result in the direct transport of soil particles or sediment and associated nutrients into nearby surface water (Haygarth et al. 2005). Surface runoff as saturated overland flow can also carry nutrients to surface water in dissolved forms (Nash and Halliwell 2000). Infiltration or leaching involves the movement of water from the surface through the soil matrix either by preferential flow through macropores, or flow through soil that has not reached its infiltration capacity (Baker et al. 2008), settling in shallow groundwater and eventually making its way to surface water (Cooke et al. 2005).

The contribution of agriculture to accelerated eutrophication of surface waters (Sims et al. 2000; Smil 2000; Bennett et al. 2001) is well recognized, especially in the United States (Sharpley et al. 1987, 1999; Carpenter et al. 1998) and Europe (Isermann 1990; Smith et al. 2001a; Smith et al. 2001b). Agricultural inputs of N and P into soil in the form of inorganic fertilizers or livestock manure are essential for profitable crop production. However, excessive application of nutrients beyond crop utilization and removal can lead to nutrient accumulation in the soil. Nutrients accumulated on the soil surface are susceptible to loss in surface runoff. Runoff from agricultural land is one of the major sources of non-point source pollutants, particularly bioavailable P, which can impair water quality in lakes and streams (Sharpley 1993; Daniel et al. 1994).

Soil-test phosphorus level is an estimate of plant-available P. In many areas of the world, long-term trends in STP values have shown that soil P is now greater than crop requirements (Sims et al. 2000). In areas of intensive crop and livestock production in Europe (Barberis et al. 1995; Hooda et al. 1997), the United States (Daniel et al. 1993; Sharpley et al. 1996; McDowell et al. 2002), and Canada (Campbell et al. 1986; Simard et al. 1995), P has accumulated in soils to levels that are more of a concern for long-term eutrophication risk rather than an agronomic risk (Sharpley and Withers 1994; Sharpley 1995; Carpenter et al. 1998; Hooda et al. 2001; Sharpley et al. 2001). Manure from intensive livestock and concentrated animal feeding operations (Figure 1.4) in many parts of the world have led to water quality problems, and there is a need to improve nutrient management to avoid

Figure 1.4. Manure spreading on land.

problems associated with surplus nutrients entering the environment (Hooda et al. 2000; Sims et al. 2000).

Soil-test phosphorus values in Alberta are generally less (≤ 25 mg kg^{-1}) (Manunta et al. 2000) than the agronomic threshold of 60 mg kg^{-1} (Howard 2006). However, there are fields in Alberta that have been measured with excessive STP levels (>200 mg kg^{-1}) as a result of repeated manure application (Svederus et al. 2006; Little et al. 2007). Several research studies in Alberta have shown the effects of manure application on the accumulation of N and P in soil (Chang and Janzen 1996; Chang et al. 2005; Olson and Papworth 2006; Olson et al. 2009, 2010a,b). Surveys have shown that about 64% of Alberta farmers apply varying amounts of manure to their crop land (Brethour et al. 2007). This compares to reported rates in Saskatchewan (43%); Manitoba (65%); Ontario (75%); and Quebec (78%) (Brethour et al. 2007). The survey also revealed that in Alberta, producers who use manure only applied manure to 22% of their land and only 34% of the producers that apply manure in Alberta used a formal manure management plan.

An initial water quality survey was conducted in Alberta in 1995 and 1996 on 27 streams and 25 lakes in runoff-prone agricultural areas (CAESA 1998) (Figure 1.5). The associated watersheds were classified as low, moderate, or high agricultural intensity based on livestock manure production, pesticide sales, and fertilizer sales. The study found that 99% of the high, 88% of the moderate, and 89% of the low intensity agricultural streams exceeded the Surface Water Quality Guidelines for TP in Alberta (0.05 mg L^{-1}) (Alberta Environment 1999). The corresponding exceedence values for TN (surface water guideline of 1.0 mg L^{-1}) were 87%, 65%, and 32%, respectively. Similarly, 96% of lakes in high intensity and 38% of lakes in low intensity areas exceeded the TP guideline. Recently, the TN and TP guidelines were withdrawn in Alberta and replaced with narrative statements in recognition for site-specific objectives (ESRD 2014).

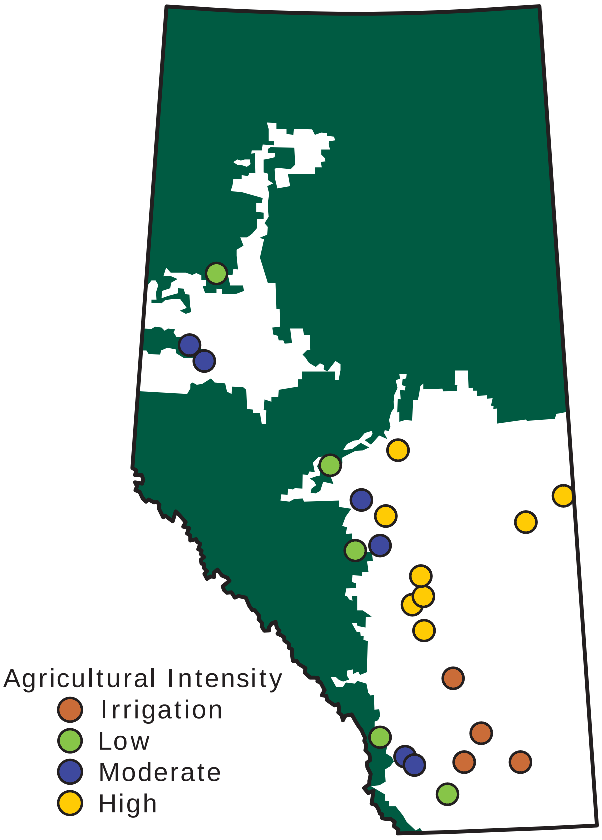


Figure 1.5 AESA water quality monitoring watersheds.

Following the CAESA study, the AESA long-term study continued monitoring 23 small agricultural watersheds in Alberta (Lorenz et al. 2008). This study found that in general, agricultural intensity influenced N and P concentrations such that higher agricultural intensity watersheds yielded higher N and P concentrations, while low intensity watersheds yielded lower N and P concentrations.

A three-year study of eight different agricultural micro-watersheds in Alberta by Little et al. (2007) examined STP values in soil. In some areas, STP values ranged from 200 to 500 mg kg^{-1} (Little et al. 2007), which is much higher than the agronomic threshold value of 60 mg kg^{-1} (Howard 2006). Little et al. (2007) found a direct linear relationship between STP and runoff P concentration. They also found that DRP, TP, and degree of soil P saturation were greater in manured, cultivated fields than in non-manured, cultivated fields and at an ungrazed grassland site.

1.2.3 Sediment

Sediment loss and transport from land to surface waters is often related to the intensity of rainfall, physical and chemical attachment between various solid components, and the amounts and velocity of runoff waters (Guy 1970). Sediment and nutrient loads often occur co-dependently, but sediment itself is also a physical parameter of water quality. The amount of suspended sediment in surface water has implications for turbidity, light penetration, and temperature.

Rainfall and snowmelt events drive water erosion of soil, which in turn affects surface water quality in Alberta. Jedrych and Martin (2013) developed a water erosion potential map for agricultural land in Alberta, where erosion rates were calculated as functions of area-specific information relating to climate, soil, landscape conditions and a uniform land-use scenario. Predicted erosion rates ranged from 0 to 783 Mg ha^{-1} yr^{-1}. As expected, Jedrych and Martin (2013) found that highest erosion rates were on hill slopes adjacent to river valleys, and the lowest rates were on flat land.

1.2.4 Microorganisms

Livestock manure, particularly untreated slurry and feces of grazing animals, can carry a variety of bacterial, protozoan, and viral microbes from diseased and carrier animals (Mawdsley et al. 1995; Hooda et al. 2000). Microbial contamination of water supplies may occur as a consequence of leakage from manure in buildings or storage facilities, application of manure to land, direct access of livestock to streams, and feces deposited on pasture by grazing animals (Figure 1.6). Mawdsley et al. (1995) listed 11 bacteria, three viruses, and four protozoa (parasites) from livestock waste that may cause human diseases. Wildlife may also play a role in microbial contamination of waters (Niemi and Niemi 1991). Since microbes can survive for long periods in the environment, it is a matter of concern not only for livestock health but also for human health, which can be affected through contact with contaminated water.

Figure 1.6. Cattle direct access to a river.

Microbes can be transported in surface runoff (Tyrrel and Quinton 2003) in addition to nutrients and other contaminants. Microbes in runoff have been reported from manure-applied fields (Patni et al. 1985; Thornley and Bos 1985), grazed pastures (Doran and Linn 1979; Doran et al. 1981;

Howell et al. 1995), barnyard and manure piles (Thornley and Bos 1985), and feedlots (Young et al. 1980). Assessment of runoff bacteria is generally achieved through the use of indicators such as total coliforms, fecal coliforms, fecal streptococci, or enterococci. *Escherichia coli* (*E. coli*) are also used as indicator organisms for detecting environmental fecal pollution (Mawdsley et al. 1995). Lorenz et al. (2008) found a strong relationship between total suspended sediment and median annual concentrations of fecal coliforms ($r = 0.775$, $P<0.005$) and *E. coli* ($r = 0.782$, $P<0.005$) for 23 agricultural streams in Alberta, suggesting that streams with higher suspended sediment are more likely to have higher bacteria concentrations.

It is also recognized that fecal coliforms can exist in the environment for long periods of time. High concentration of fecal coliforms in runoff can persist for more than one year after cattle are removed from a grazed area (Jawson et al. 1982). Bacteria persisted in the soil for at least two years after application of dairy manure slurry on a grassland was stopped (Bittman et al. 2005), for 143 days for *Salmonella* after application of liquid pig manure (Gessel et al. 2004), and for 60 days for *E. coli* after cattle were removed from a grassland (Oliver et al. 2005). However, studies to date have not found statistically significant relationships between bacterial concentrations in water and confined feeding operations (Johnson et al. 2003; Little et al. 2003).

Escherichia coli have been reported to peak in surface water during the warmest months of the year (Hyland et al. 2003; Johnson et al. 2003) and the “first flush” phenomenon occurs when there is a rise in bacteria at the onset of a precipitation event following a period of dry weather (Tong and Chen 2002). Gannon et al. (2005) determined that *E. coli* in southern Alberta reservoirs did not originate from in-stream sediments, but rather from non-point sources. Sedimentation of bacteria in local reservoirs may pose a potential human health risk as bacterial concentrations can be up to 1000 times greater in sediments compared to the water column (Hendricks and Morrison 1967; Gannon et al. 2005).

1.3 Beneficial Management Practices

Several different BMP options are available to producers to minimize the environmental impacts of their farm operations (Figure 1.7). Different farm operations require different BMPs, and much of the literature has grouped BMPs into several categories. For instance, Sharpley et al. (2006) differentiates between source and transport BMPs and argues that the goal of source BMPs are to reduce nutrient loss at the source by minimizing buildup of nutrients in the soil. Source BMPs include practices such as livestock relocation and improved manure storage. It may be more desirable to implement source BMPs as it is less costly to prevent nutrient loss than to treat the effects.

Transport BMPs are practices that control the movement of nutrients from soil to waterway by limiting runoff, erosion, and leaching (Sharpley et al. 2006). Examples of transport BMPs include conservation tillage, irrigation management, and stream slope stabilization (bioengineering). Rao et al. (2012) categorized BMPs into structural and management groups. Structural BMPs include the physical structures and buildings that incur one-time construction costs and subsequent maintenance costs, such as manure storage facilities or detention ponds. Management or non-structural BMPs are strategies that reduce the quantity of

Figure 1.7. Examples of beneficial management practices: (a) off-stream watering; (b) control of cattle access to water with fencing; (c) injection of liquid manure; and (d) grass channel.

contaminants without a structural facility and are implemented on a continuous basis, such as changing manure application practices (Chang et al. 2007). Table 1.1 provides an overview of different BMP options.

While several BMPs have been developed for managing livestock manure, and nutrient management in general, it is unlikely that a single BMP will effectively reduce or eliminate negative environmental impacts. Often, it is a combination of BMPs that will result in reduced environmental impacts (Bishop et al. 2005; Sharpley et al. 2006; Chaubey et al. 2010). Li et al. (2011) monitored two individual BMPs and a suite of three BMPs to assess their effects on water quality within an agricultural watershed in south-central Manitoba. It was concluded that the combination of all five BMPs was effective at reducing nutrient loss but that effects of individual BMPs were difficult to discern due to varying factors. Arguably, the main decision facing producers is to decide which combination of BMPs is best suited to their operations (Sharpley et al. 2006).

1.3.1 BMP Effectiveness

The effectiveness of BMPs on the aquatic environment can be measured by several parameters such as surface flow, species richness, soil conditions, riparian quality, and water quality. Within Canada and the United States, several studies examined the effectiveness of BMPs at field and watershed scales, and some have conducted economic feasibility analyses. Examples of two major research projects are the Watershed Evaluation of Beneficial Management Practices (WEBs) Project in Canada (AAFC 2007), and the Conservation Effects Assessment Project (CEAP) in the United States (USDA 2008). Primarily focused on water quality, the WEBs project was initiated at seven small watersheds across Canada in order to assess the environmental and economic performance of different BMPs and to inform policy and decision making. At each watershed, a suite of BMPs were selected and applied to match the conditions of each individual watershed (Stuart et al. 2010). It was found that more than half of the BMPs had the potential to reduce contaminant loading to surface waters (Stuart et al. 2010).

One of the main goals of the CEAP was to establish scientific understanding and quantification of the effects of conservation practices at the watershed scale in 13 sites

Table 1.1. A summary of beneficial management practice options.

BMP	Type^z	Description and purpose	Evaluated in this study	Supporting literature
Grazing management	S, M, L	• decreases soil loss and direct transfer of fecal matter and nutrients by separating livestock and streams, and maintaining riparian vegetative cover	Yes	• Owens et al. 1996 • Sheffield et al. 1997 • Schwarte et al. 2011
Manure storage areas	S, St	• prevents manure from leaching into the ground or ending up as runoff	No	• Fullhage 1997 • Inamdar et al. 2002
Stream bank stabilization (bioengineering)	T, St	• stabilizes steep stream slopes to prevent water contamination by erosion with use of biological, mechanical, and ecological concepts	Yes	• Meals 2001 • Barret et al. 2006
Irrigation management	T, M, C	• efficient use of water and minimal erosion and runoff by determining and controlling the rate, amount, and timing of irrigation water application, and use of water-efficient equipment	Yes	• AAFRD 2004 • Sharpley et al. 2006
Manure composting	S, St	• increased retention of nutrient and coliform bacteria, and more uniform application of nutrients	No	• Fitzpatrick et al. 2005 • Larney et al. 2006
Conservation tillage	T, M, C	• reduces transport of sediment and sediment-bound nutrients	No	• Ziemen et al. 2006 • Tiessen et al. 2010
Riparian buffer zones	T	• reduce nutrient loading to adjacent streams by retaining and transforming nutrients	Yes	• Duchemin and Hogue 2009 • Hoffman et al. 2009
Grassed waterways	T	• reduce runoff and erosion, filters sediment	Yes	• Chow et al. 1999 • Inamdar et al. 2002
Artificial wetlands, lagoons, and sediment basins	T, St	• reduces nutrient transport by capturing nutrient-enriched runoff	No	• Cronk 1996 • Li et al. 2011
Manure/fertilizer application management	S, M	• minimizes nutrient loss in runoff	Yes	• Srinivasan et al. 2006 • Easton et al. 2008

^{z} Type denotes if the BMP is source (S), transport (T), structural (St), management (M), crop (C), or livestock (L).

throughout the United States (Duriancik et al. 2008). The different BMPs used in the study included irrigation management practices, conservation buffers, nutrient management, and tillage management (Duriancik et al. 2008). It was found that:

- Constructed wetlands reduced the movement of nitrate from tile-drained fields to streams;
- Riparian buffers were effective in mitigating the loss of nutrients and bacteria in runoff; and
- Fertilizer management techniques reduced nitrate losses from fields (Richardson et al. 2008).

The WEBs and CEAP studies were able to show the ability of BMPs to improve surface water quality as well as the quality of nearby soils and habitat.

1.3.2 Experimental Design

There are three common approaches used to evaluate the effectiveness of agricultural BMPs on water quality: paired watershed design; before-after monitoring; and upstream-downstream designs (Spooner et al. 1985; Sheffield et al. 1997; Grabow et al. 1998; Mostaghimi et al. 2001). In some instances, it may be appropriate to combine these approaches into the same monitoring program.

The paired watershed approach consists of two or more watersheds where at least one watershed experiences BMP implementation (i.e., treatment watershed) and at least one watershed remains unchanged (i.e., reference or control watershed) (Spooner et al. 1985). It is assumed that two or more nearby watersheds with similar physical properties (i.e., soils, land use, climate) will respond in predictable manners. Both watersheds experience the same monitoring regime and the temporal trends of response variables are compared between the control and treatment watersheds (Lemke et al. 2011). Paired watershed designs often also use the before-after approach, which is discussed below.

In the before-after approach, water quality data are collected from a location downstream of the BMP for a period of time before and after BMP implementation (Grabow et al. 1998). The before-after approach for a single watershed does not use a control watershed (Mostaghimi et al. 2001). However, when before-after designs are combined with a paired watershed approach, water quality data are collected from a control watershed and a treatment watershed at time periods before and after BMP implementation. Any improvements in water quality may be indicative of the BMP.

The upstream-downstream approach is typically only used with single-watershed studies (Grabow et al. 1998). If a larger water body is used, this design requires that the water from a BMP site directly enter the stream or river being monitored, thus allowing for the differentiation between water upstream and downstream of the BMP site (Mostaghimi et al. 2001). It is assumed that changes in the response variables are due to BMP implementation (Miller et al. 2010).

Monitoring frequency, baseline sampling, and event-based sampling must take into account the experimental design chosen. For example, if sampling is too frequent, autocorrelation of data may occur. If sampling is too infrequent, critical information may be missed (Mostaghimi et al. 2001). A monitoring program should be long enough to capture variations in watershed hydrology response to weather (i.e., storm or rainfall-runoff) events (Easton et al. 2008; Duchemin and Hogue 2009). However, it should also include event-based monitoring because nutrient loss from a watershed is largely a result of rainfall-runoff events (Sharpley et al. 2008).

1.3.3 Computer Models

Watershed and hydrologic models are useful tools to simulate water quality response in streams. Such models are valuable because they can evaluate BMP effectiveness in agricultural watersheds and results can be used to inform management decisions (Easton et al. 2008; Chaubey et al. 2010). A popular and extensively developed tool for hydrology studies is the Soil and Water Assessment Tool (SWAT), which has been widely used in studies examining the impact of land use activities on quality of surface water (Santhi et al. 2001; Secchi et al. 2007; Yang et al. 2007; Chaubey et al. 2010; Jha et al. 2010). The SWAT model is applicable to small watersheds and river basins and simulates the quality and quantity of surface and ground water related to land management decisions, and is used in assessing non-point source pollution management in watersheds (USDA 2013).

Several studies suggest using watershed models to simultaneously assess economic costs and environmental benefits associated with BMP implementation (Secchi et al. 2007; Yang et al. 2007). Yang et al. (2007) highlighted several challenges associated with implementing BMP or conservation programs, such as unknown costs and adoption rates of BMP implementation, accounting for complex contaminant transport processes, and understanding trade-offs between economic and environmental effects. The authors provided an integrated economic-hydrologic modelling framework to evaluate the economic and environmental performances of BMP implementation. The framework includes an on-farm economic model, a farmer adoption behaviour model, a watershed modelling tool box, and a non-market valuation model (Yang et al. 2007).

1.4 Project Objectives

Since the early 1990s, Alberta recognized that agriculture impacts on water quality were a significant concern, and the province initiated a strategic plan to assess the issues, identify the causes, and implement research projects that would provide science-based solutions that government and producers could support. This strategic plan to successfully mitigate agricultural water quality concerns recognized that before producers are likely to invest in selected BMPs, they need assurance that their investment will have a positive impact on the environment and are practical to implement.

Figure 1.8 outlines the mitigation continuum being followed in Alberta Agriculture and Rural Development to achieve a long-term, effective mitigation and optimum protection of surface water quality in agricultural watersheds. This figure also identifies how the BMP Project relates to earlier monitoring and research studies in Alberta along the mitigation continuum.

The objective of the BMP Project was to design and implement a targeted suite of BMPs at field sites in selected watersheds that represented agricultural management practices in Alberta. The main focus of the BMPs in this study was to improve surface

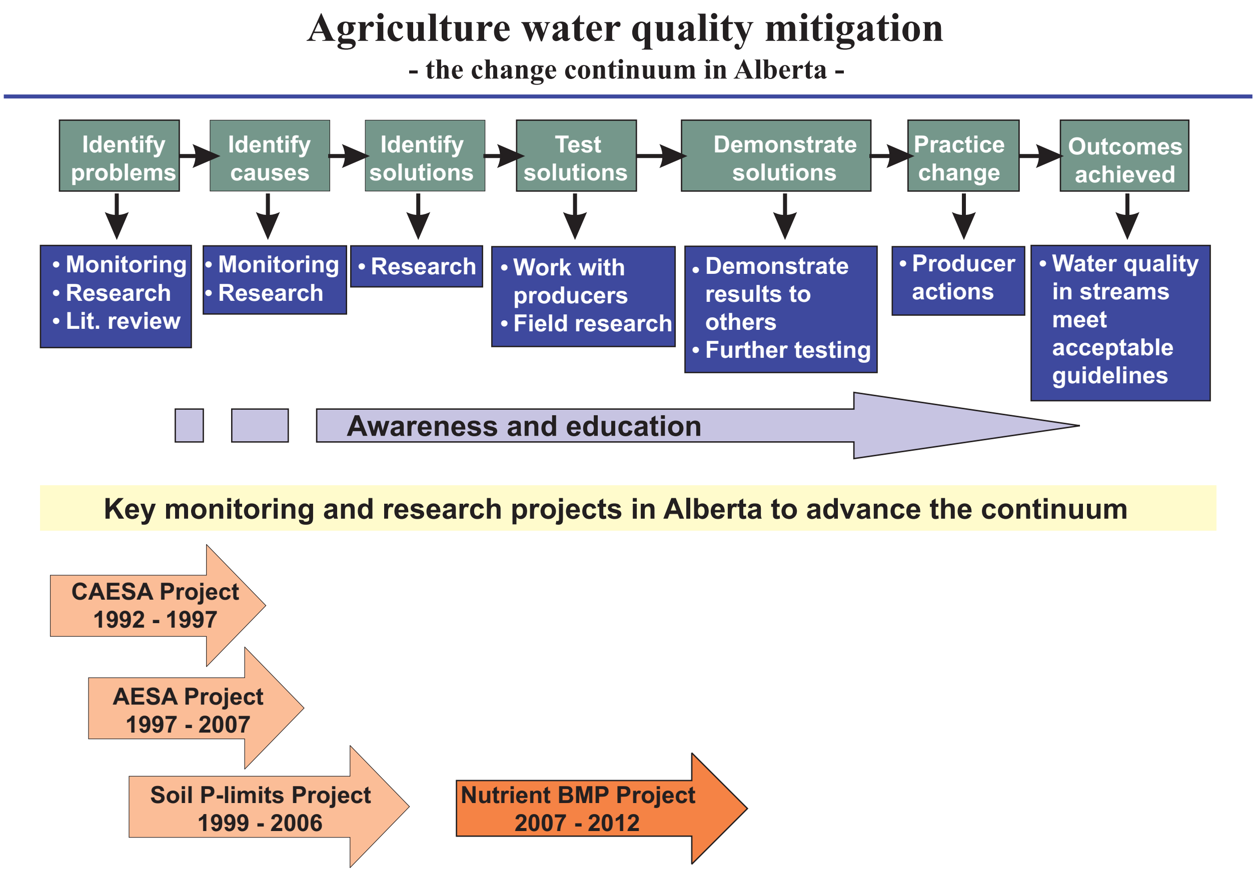


Figure 1.8. Water quality mitigation change continuum.

water quality. However, other indicators such as riparian and rangeland quality were also assessed. This study evaluated three main BMP categories: manure management by land application (nutrient management); livestock management; and surface-water management. The specific project objectives were to:

- Evaluate the effectiveness of nutrient BMPs in reducing agricultural impacts on the environment at the farm scale;
- Assess the impacts of BMPs on water quality in specific reaches of a watershed stream;
- Predict the cumulative impacts 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.

2 BMP STUDY SITES

2.1 Study Sites

Two main watersheds were selected for this study, as well as two individual field sites at separate locations (Figure 2.1) (ARD 2014b). The Indianfarm Creek (IFC) Watershed (14,145 ha) is in southwestern Alberta, and the Whelp Creek (WHC) Sub-watershed (4595 ha) is in central Alberta. The two field sites were near Lethbridge: one (65 ha) in the Battersea Drain Watershed Field (BDF) and the other (130 ha) in the Lower Little Bow River Watershed (LLB). These two field sites were irrigated and located in an intensive livestock feeding area. Both sites had a history of extensive beef manure application.

Several factors were considered in the selection of the watersheds. The primary physical factor was hydrologic — runoff from selected watersheds was a requirement during the project time-frame. In addition, agricultural intensity and diversity, with little or no non-agricultural influences were important considerations. Also important was the level of producer cooperation — a critical requirement for any successful field research project.

The IFC Watershed was rated as moderate agriculture intensity and the WHC Sub-watershed was rated as high agriculture intensity, based on the methodology described by Anderson et al. (1999) and Johnson and Kirtz (1998), and used for the Alberta Environmentally Sustainable Agriculture Water Quality Monitoring Project (Lorenz et al. 2008). Agriculture intensities were based on agriculture census data of pesticide sales, fertilizer sales, and manure production. Both watersheds have crop and livestock production.

A total of 22 BMP and Reference sites were assessed within the selected watersheds. Site locations are shown in Figures 2.2, 2.3, and 2.4, and site descriptions are shown in Table 2.1. The BMP plan for each site included a suite of BMPs that were specifically designed to mitigate existing water quality concerns. The BMPs were implemented and assessed during a two- to four-

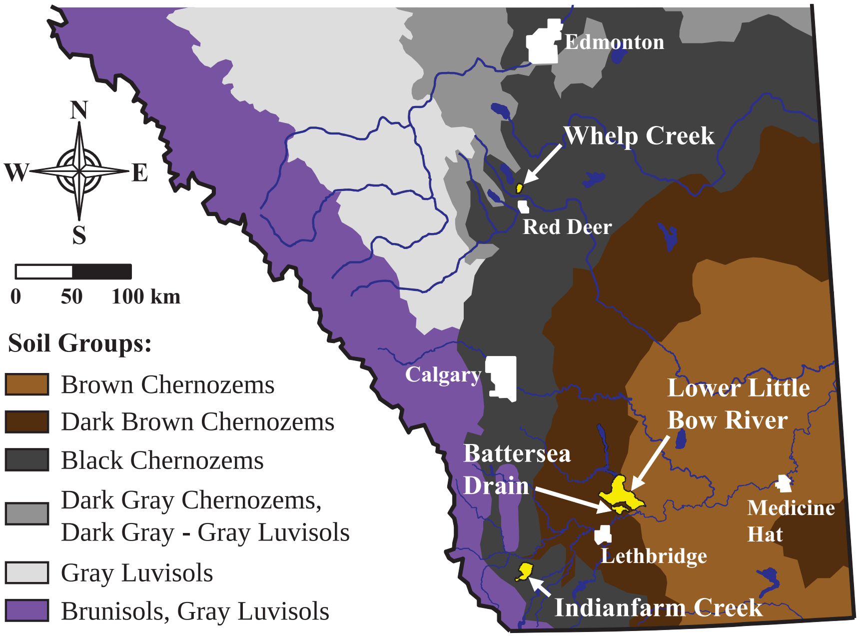


Figure 2.1. Location of the Nutrient Beneficial Management Practices Evaluation Project research sites.

year time frame if possible. The BMP sites were grouped into three general management categories.

- **Cattle management**: Included infrastructure alterations; off-stream watering; windbreaks; fencing; bioengineering; and/or improved grazing plans.
- **Manure nutrient management**: Included cropland and modified nutrient management plans; setback areas from water bodies; and/or buffer zones.
- **Surface-water management**: Included berming and redirecting flow of surface water; or irrigation management to reduce runoff.

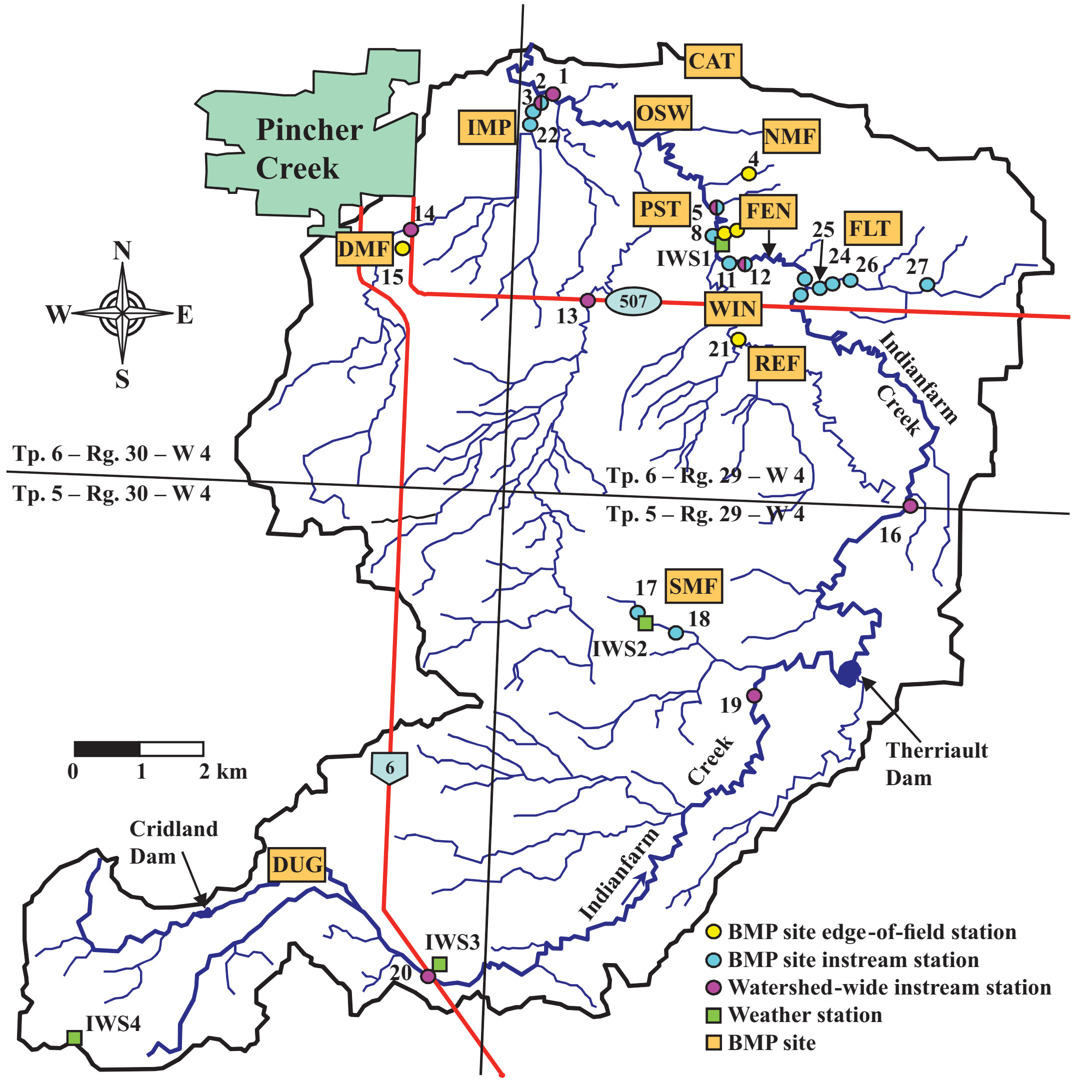


Figure 2.2. Beneficial management practices sites and water quality monitoring stations in the Indianfarm Creek Watershed.

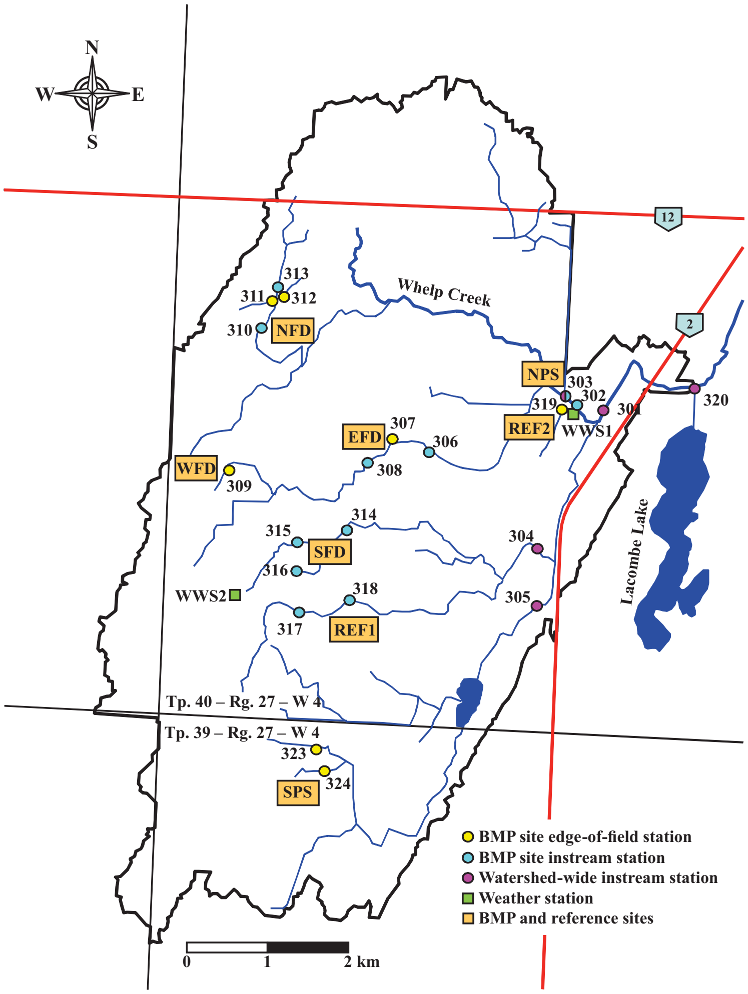


Figure 2.3. Beneficial management practices sites and water quality monitoring stations in Whelp Creek Sub-watershed.

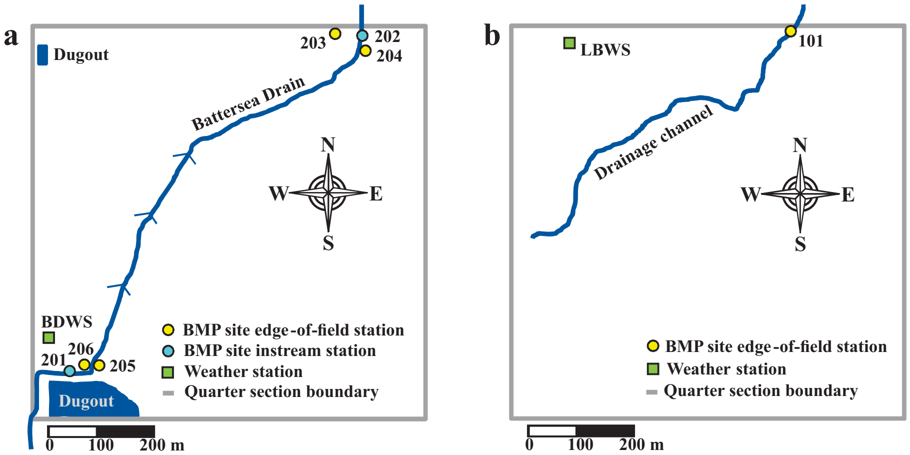


Figure 2.4. Water quality monitoring stations at the Battersea Drain Field and Lower Little Bow Field beneficial management practices sites.

Table 2.1. 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.

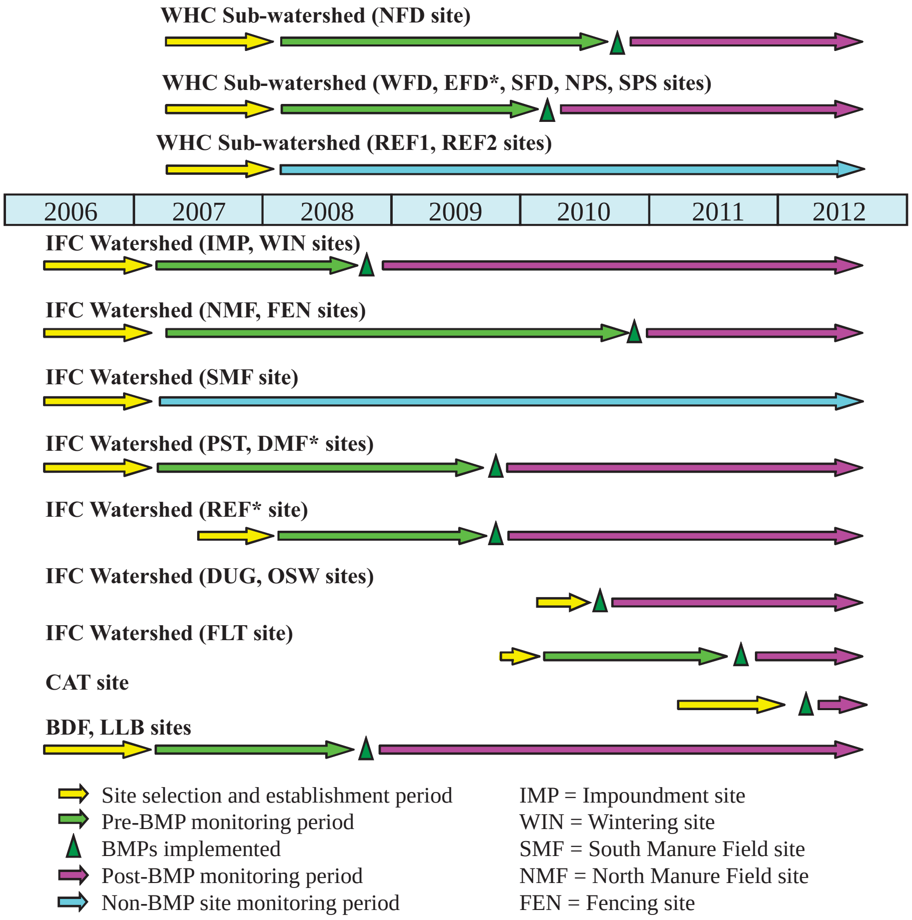
[w] Due to various factors, a BMP plan was not implemented at the SMF.

[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.

Figure 2.5 provides an overview of the site selection and pre- and post-monitoring timelines for each BMP site.

2.2 Research Plan

This study adopted the before-and-after experimental design approach. The selected BMP sites were monitored for two to four years under existing management practices to measure the status of various indicator parameters (e.g., water quality, riparian quality) prior to BMP implementation. In cooperation with the producers, BMP plans were developed and implemented and the sites were monitored for another two to four years after BMP implementation.



WFD = West Field site
NFD = North Field site
SFD = South Field site
EFD = East Field site
NPS = North Pasture site
SPS = South Pasture site
REF1 = Reference 1 site
REF2 = Reference 2 site

IMP = Impoundment site
WIN = Wintering site
SMF = South Manure Field site
NMF = North Manure Field site
FEN = Fencing site
PST = Pasture site
DMF = Dairy Manure Field site
REF = Reference site
DUG = Dugout site
OSW = Off-stream Watering site
FLT = Feedlot site
CAT = Catch Basin site
LLB = Lower Little Bow River Field site
BDF = Battersea Drain Field site

* Implementation of BMPs was not successful

Figure 2.5. Implementation timelines for the Nutrient Beneficial Management Practices Evaluation Project sites.

The main focus was on water quality; however, other indicators, such as soil, rangeland quality, and riparian quality, were used where applicable (Table 2.2). Water quality parameters (N, P, sediment, and bacteria) were monitored:

- Upstream and downstream of the BMP sites; or
- At edge-of-field sites; or
- A combination of the two.

Table 2.2. Overview of the data types collected at the beneficial management practice sites.

BMP site			Data types collected														
Site[z]	BMP plan developed	BMPs implemented	Agronomic management	Water quality	Water flow	Soil	Riparian quality	Rangeland quality	Rangeland production	Manure	BMP costs	Bioengineering costs	Photo points	Crop yield	Hydrology survey	Cattle and fecal pat counts	Irrigation volume and timing
Indianfarm Creek Watershed																	
IMP	✓	✓	✓	✓[y]	✓		✓				✓	✓					
NMF	✓	✓	✓	✓	✓	✓					✓			✓		✓	
PST	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓					
WIN	✓	✓	✓	✓	✓		✓				✓	✓					
SMF	✓		✓	✓	✓	✓				✓				✓			
DMF	✓	✓	✓	✓	✓	✓				✓	✓			✓			
REF	✓	✓	✓	✓	✓	✓					✓			✓			
FLT	✓	✓	✓	✓	✓			✓			✓		✓		✓		
DUG	✓	✓	✓				✓				✓		✓				
OSW	✓	✓	✓				✓				✓		✓				
CAT	✓	✓	✓								✓				✓		
FEN	✓	✓	**na**[x]								✓						
Whelp Creek Sub-Watershed																	
WFD	✓	✓	✓	✓	✓	✓				✓	✓			✓			
NFD	✓	✓	✓	✓	✓	✓				✓	✓			✓			
EFD	✓		✓	✓	✓	✓				✓	✓			✓[w]			
SFD	✓	✓	✓	✓	✓	✓				✓	✓			✓			
NPS	✓	✓	✓	✓	✓	✓			✓		✓	✓	✓				
SPS	✓	✓	✓	✓	✓	✓			✓		✓						
REF1			✓	✓	✓	✓								✓			
REF2			✓	✓	✓	✓								✓			
Irrigated field sites																	
LLB	✓	✓	✓	✓	✓	✓				✓	✓			✓			✓
BDF	✓	✓	✓	✓	✓	✓				✓	✓			✓			✓

[z] BDF = Battersea Drain Field, CAT = Catch Basin, DMF = Dairy Manure Field, DUG = Dugout, EFD = East Field, FEN = Fencing, FLT = Feedlot, IMP = Impoundment, LLB = Lower Little Bow Field, NFD = North Field, NMF = North Manure Field, NPS = North Pasture, OSW = Off-stream Watering, PST = Pasture, REF = Reference, REF1 = Reference 1, REF2 = Reference 2, SFD = South Field, SMF = South Manure Field, SPS = South Pasture, WFD = West Field, and WIN = Wintering.

[y] Includes a one-time water sampling from several locations and depths from the impoundment lake.

[x] na = not applicable.

[w] Crop yield samples obtained by collecting square quadrant samples. Yield values were provided by cooperating producers for the other BMP sites with crops.

3 DATA COLLECTION AND ANALYSIS

3.1 Weather Data

Regional weather data were obtained from Environment Canada weather stations nearest to the study areas and these data were used for the time period before study weather stations were installed in the watersheds. Environment Canada data were also used throughout the study period for comparison and validation of the weather data collected within the watersheds. The data acquired included total daily and monthly precipitation and monthly average daily temperature. Analysis of weather events and trends during the project were compared to the 30-year normal values (1971 to 2000) provided by Environment Canada (2013).

In 2008, automated weather stations were installed at the study areas to provide site specific weather data. These data were used in the calibration process of the Soil and Water Assessment Tool (SWAT) and Agricultural Policy/Environmental eXtender (APEX) models (Jedrych et al. 2014a). Four weather stations were used at the IFC Watershed, two at the WHC Sub-watershed, and one at each of the two irrigated field sites (BDF and LLB). Weather data included air temperature, relative humidity, and precipitation. Data were collected from these stations for three full years (2009 to 2011) and only for a portion of 2008 and 2012.

3.2 Land Use and Land Cover

Three methods were used to collect land use and land cover data.

- Visual survey using the AgCapture Program — A land-cover information collection computer program, developed by the former Prairie Farm Rehabilitation Administration, was used to inventory and map land-cover distribution in the IFC and WHC watersheds.
- Producer interviews — A one-time survey was carried out through in-person interviews in the watersheds and the two irrigated field sites at the start of the project. Comprehensive data on cropping rotations, livestock practices, grazing management, equipment used, and nutrient management were collected.
- Annual producer updates — Annual management updates were obtained from the cooperating producers that had BMP evaluation sites on their properties. Information included crop types, seeding and harvest dates, yield, fertilizer and pesticide use, manure application, number of livestock, and grazing rotations.

3.3 Water Flow and Quality Monitoring

Three types of water monitoring stations were used in this study: BMP site edge-of-field stations; BMP site in-stream stations; and watershed-wide in-stream stations (Figures 2.2, 2.3, and 2.4). Edge-of-field stations were located in defined channels either near or at the edge of the field. These stations were used to measure flow and collect water samples before runoff entered a ditch, creek, or tributary. Watershed-wide, in-stream stations monitored changes in flow and water quality as water travelled through the watersheds.

3.3.1 Water Flow Monitoring

All watershed-wide and BMP site instream stations were instrumented with circular flumes (Samani et al. 1991) (Figures 3.1 and 3.2), pressure transducers (Figures 3.3 and 3.4b), acoustic Doppler velocity meters (Figure 3.4a), or staff gauges (Figure 3.4c) for flow measurement. Edge-of-field monitoring stations at the BMP sites were instrumented with circular flumes for flow measurement. Float potentiometers were used with the circular flumes to measure height of water (Figure 3.2).

For stations equipped with staff gauges and Level TROLLs, flow metering to develop rating curves was completed using (1) a StreamPro acoustic Doppler current profiler (Teledyne RD Instruments, Poway, California); (2) a FlowTacker acoustic Doppler velocity meter (Teledyne RD Instruments, Poway, California); or (3) a Swoffer current velocity meter (Swoffer Instruments Inc., Seattle, Washington) (Figures 3.5 and 3.6).

3.3.2 Water Quality Monitoring

Water samples were collected either with automatic Isco samplers or manually by grab sampling. Sampling frequency was flow-event based (e.g., high flow versus base flow for instream). All edge-of-field BMP stations and nearly all in-stream BMP stations were equipped with either a Model 3700 or Model 6712 Isco automated water sampler (Teledyne Isco, Lincoln, Nebraska; Figure 3.7). The edge-of-field flumes and float potentiometers automatically triggered the Isco samplers during flow events. The Isco samplers then sampled a 75-mL volume every 15 min for 24 hours or until the runoff stopped, whatever occurred first (Figure 3.8). Stations without Isco samplers were grab sampled.

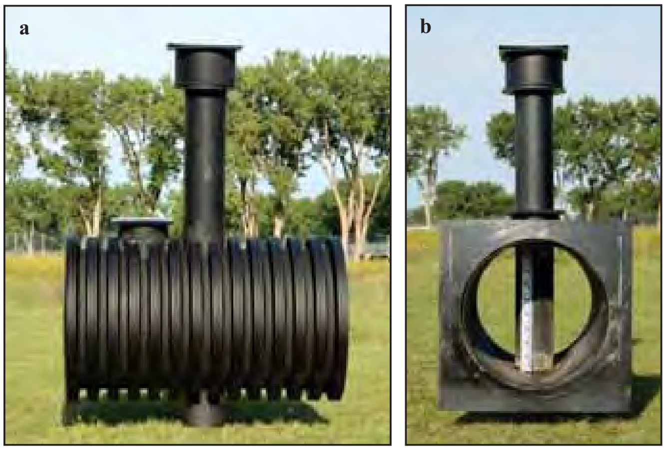


Figure 3.1. Side and front profile views of a 0.9-m diameter circular flume.

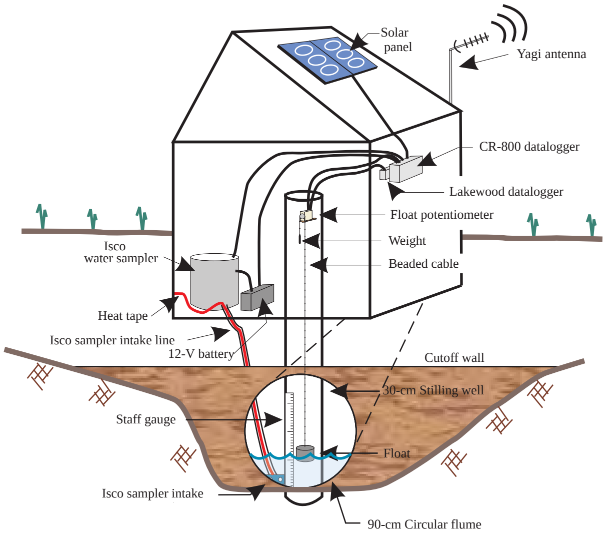


Figure 3.2. Schematic of edge-of-field monitoring station instrumentation.

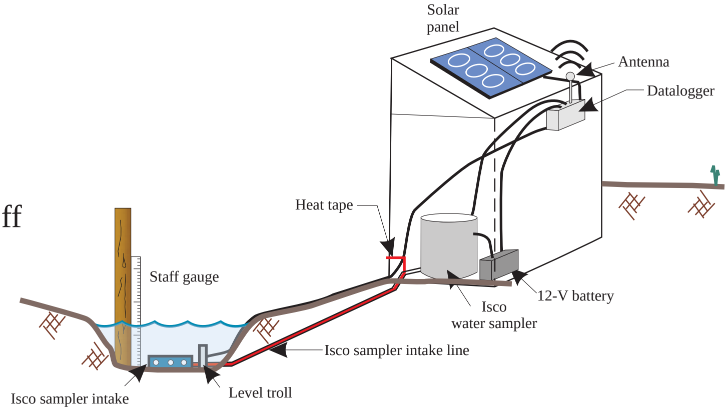


Figure 3.3. Schematic of instream monitoring station instrumentation.

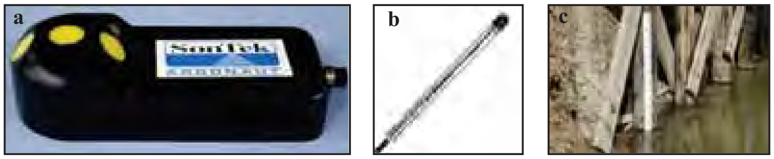


Figure 3.4. Pictures of (a) Argonaut SW acoustic Doppler velocity probe, (b) Level TROLL 700 pressure transducer, and (c) staff gauge.

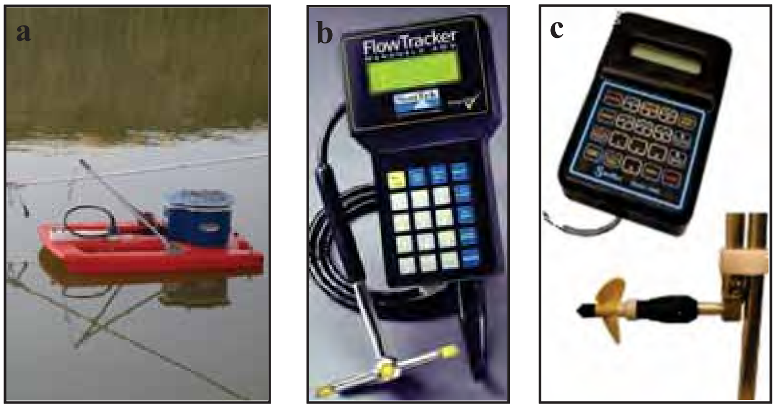


Figure 3.5. Equipment used for flow metering: (a) StreamPro, (b) Flow Tracker, and (c) Swoffer velocity meter.

Figure 3.6. Flow metering using (a) StreamPro with rope system, and (b) wading instream with a Flow Tracker.

3.3.3 Laboratory Analysis

Water samples were sub-sampled into smaller plastic bottles provided by the laboratory for specific analyses (Figure 3.9). Sub-sample bottles, except for the bacteria bottle, were triple rinsed with sample water before filling. The bacteria bottles were filled without triple-rinsing because $Na_2S_2O_3$ preservative was in the bottles. After filling, some bottles had acid preservative added. Filled sample bottles were packed in coolers on ice in the field and transported to the nearest courier for delivery to the laboratory. Samples were analyzed for TN, nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), TP, total dissolved phosphorus (TDP), chloride (Cl), total suspended solids (TSS), *E. coli*, electrical conductivity (EC), and pH. Calculated parameters included organic nitrogen (ON) and particulate phosphorus (PP).

3.4 Soil Sampling

Nutrient Status. Each year during the study, the soil nutrient status in the 0- to 15-cm layer was determined at most of the BMP sites, except for the pasture sites (Figure 3.10). Pasture sites were sampled on one or two occasions. Samples were collected in the spring after seeding and inorganic fertilizer or manure application, and again in the fall after all field activities were completed. The spring samples represented the surface soil conditions during spring and summer rainfall events, and the fall soil samples represented surface soil conditions during snowmelt runoff in the following spring. Soil samples were also collected (0 to 60 cm) at BMP sites with annual crop fields during the post-BMP period to develop nutrient management recommendations.

Figure 3.7. Model 6712 Isco automated water sampler.

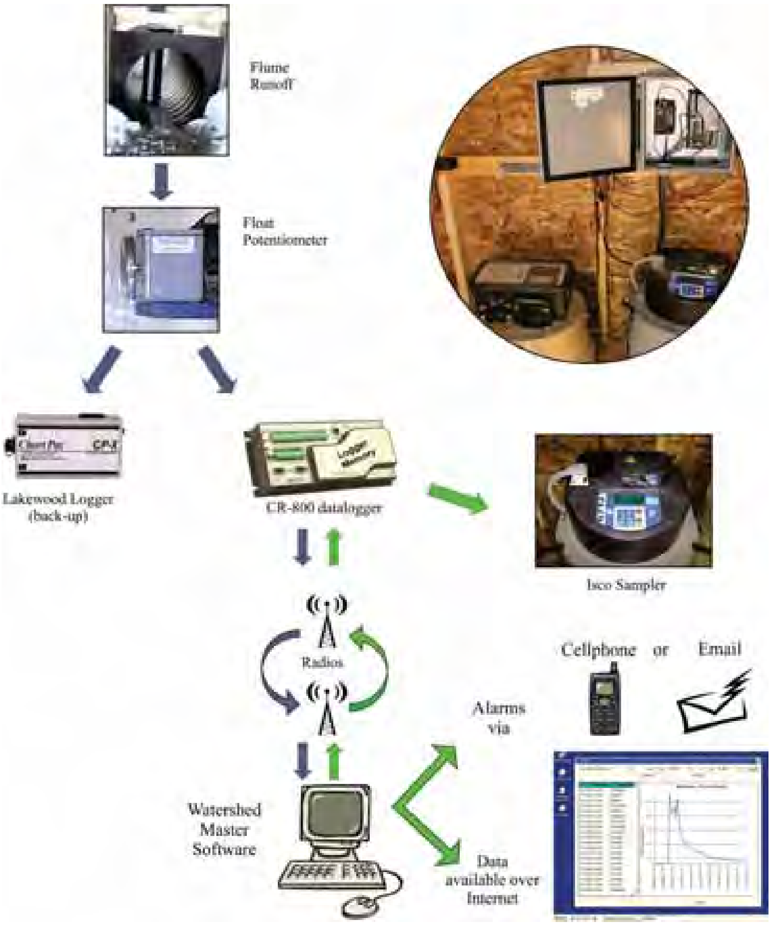


Figure 3.8. Schematic diagram of runoff event communication.

Soil samples were analyzed for extractable NO_3-N, extractable ammonium nitrogen (NH_4-N), and STP.

Irrigation Management. Soil samples were collected to obtain moisture and texture values to initialize the Alberta Irrigation Management Model (AIMM) as part of the irrigation BMP plans at the BDF and LLB sites.

3.5 Manure Sampling

Manure samples were collected either just prior to manure application or at the time of manure application at many of the BMP sites in the study watersheds. Manure types sampled included liquid hog, liquid dairy, solid chicken, and solid beef manure. Solid manures were generally sampled from stockpiles. Liquid manure samples were obtained either from the liquid manure spreader just prior to land application or when the manure spreader was filled at the manure storage facility. All manure samples were analyzed for water content, extractable NH_4-N, TN, TP, total potassium, and total sulphur. In addition, liquid manure samples were analyzed for total sodium content. Results were used to develop nutrient management plans (e.g., P based) for manure application at many of the annual crop BMP sites during the post-BMP period.

3.6 Riparian Quality

In 2007, the Alberta Riparian Habitat Management Society (Cows and Fish) completed riparian quality assessments at the IMP, WIN, and PST sites in the IFC Watershed before the livestock management BMPs were implemented. The survey results for the riparian areas of these pastures were used as a baseline riparian health score. Cows and Fish then completed post-BMP riparian evaluations in 2012 to assess the riparian quality status of each pasture at the end of the study.

From 2008 to 2012, riparian transect surveys (Figure 3.11) were completed annually at the IMP, WIN, and PST sites to evaluate riparian quality and monitor changes as a result of livestock BMPs implemented at these sites. Surveys were conducted at similar times each year so the stage of vegetative growth was comparable among years. Riparian surveys were also carried out at the OSW and DUG sites in 2011 and 2012.

In 2010, a control site was established with four transects to measure natural variability in the riparian areas of IFC without BMP implementation. As most riparian areas of IFC were grazed, a parcel of land with consistent annual grazing management was selected. Control transects were also surveyed annually.

The data collected from pre- and post-BMP surveys were compared to evaluate riparian quality in three aspects:

- Riparian zone comparisons;
- Species richness, evenness and effective diversity; and
- Cows and Fish riparian quality assessment.

Figure 3.9. Water samples being (a) sub-sampled in the field and (b) bottles for specific lab analysis.

Figure 3.10. Soil sampling with (a) a truck-mounted coring unit, and (b) a Dutch auger.

Figure 3.11. Conducting riparian surveys using (a) transects and (b) 1-m^2 quadrats.

3.7 Rangeland Quality

Beginning in 2007, rangeland-transect surveys and quality assessments (Figure 3.12) were carried out annually at the PST site to evaluate rangeland quality, based on Adams et al. (2005) and ASRD (2007). Rangeland quality assessment was also carried out at the FLT site in 2011 and 2012. Range health scores were calculated each year to obtain a cumulative measure of the quality of the pasture based on factors that affected the area selected to monitor (Adams et al. 2005). In this assessment, five categories were assessed:

- Ecological status (i.e., presence of key species of plant communities);
- Plant community structure;
- Litter cover and distribution, which is important for moisture retention;
- Site stability; and
- Presence of noxious weeds.

To complement the rangeland transects at the PST site in the IFC Watershed, production cages were placed in the pasture prior to grazing in 2008 (Figure 3.13). Production cages were also installed at the NPS and SPS sites in the WHC Sub-watershed. The production cages allowed for comparison of vegetation response and growth of the ungrazed area inside the cage to the grazed area outside the cage to determine whether the livestock management BMPs had an effect on grass, forb, and litter production.

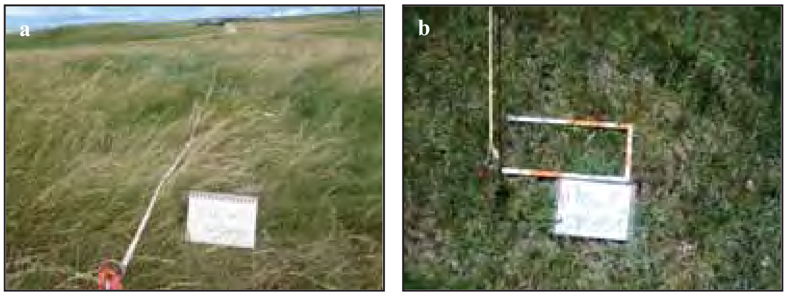


Figure 3.12. Evaluating rangeland quality along (a) a transect and (b) a 0.25-m^2 Daubenmire frame in the Indianfarm Creek Watershed.

Figure 3.13. Views of a (a) production cage and (b) 0.25-m^2 frame used to delineate vegetation to be clipped.

4 INDIANFARM CREEK WATERSHED

4.1 Introduction

Indianfarm Creek Watershed is approximately 100 km west of Lethbridge, Alberta (Figure 4.1). The approximate centre of the watershed is at 49.43° N, 113.87° W. The Town of Pincher Creek borders part of the northwest boundary of the watershed and is the only urban centre near the watershed. Total area of the IFC Watershed is 14,145 ha (141.45 km^2), or approximately 55 sections of land.

Indianfarm Creek Watershed lies in the Foothills Fescue Natural Sub-region, which is in a relatively high precipitation zone of Alberta and the topography is considered well-drained. The 30-year average (1971 to 2000) annual precipitation for the area is 515 mm (Environment Canada 2009), and estimated runoff is approximately 78 mm (Bell 1994). The watershed is in the Black Soil Zone and the soils are generally fine textured, including clay, silty clay, clay loam, and loam (Alberta Soil Information Centre 2013). The soils are susceptible to wind and water erosion and this has influenced land-use practices in the area, such as the use of zero tillage.

There are two distinct regions in the watershed: the lower region in the north and the upper region in the south (Figure 4.2). Topography in the watershed is undulating with low to high relief and hummocky with low relief. Slopes in the upper region are short, complex, and range from 2 to 9%. In the lower region, slopes are much longer and simpler, ranging from 2 to 5% with some areas ranging from 5 to 9%. The dividing area between the upper and lower regions of the watershed is very steep with slopes ranging from 12 to 20%. The distinctive change in topography between the upper and lower regions of the watershed is also evident by differences in land use and weather.

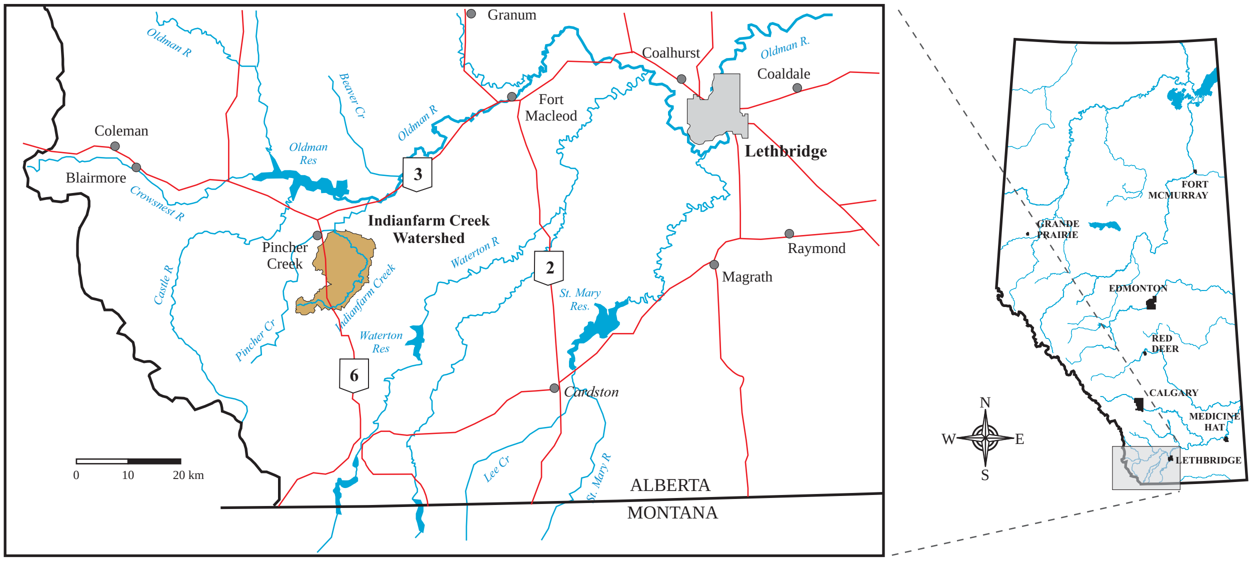


Figure 4.1. Location of the Indianfarm Creek Watershed in southwestern Alberta.

4.2 Surface Hydrology and Weather

Indianfarm Creek is the major water channel within the watershed. It is an incised and meandering creek that flows from south to north (Figure 4.2). Small tributaries drain the north-central and northwest portions of the watershed, and these tributaries flow into the northern end of IFC. Indianfarm Creek flows into Pincher Creek, which eventually reaches the Oldman River. Water flow in the creek can be deep and flashy during snowmelt and heavy rains in the spring, causing extensive bank erosion.

During the project, annual average daily temperature in IFC Watershed was similar to the 30-year average of 5°C. Annual and growing season precipitation during the study was slightly above the 30-year average (Table 4.1). The watershed was prone to particularly large (>50 mm) rain events throughout the spring and summer months. Average annual total precipitation from 2009 to 2011 was similar among the four weather stations installed in the watershed (Figure 4.3).

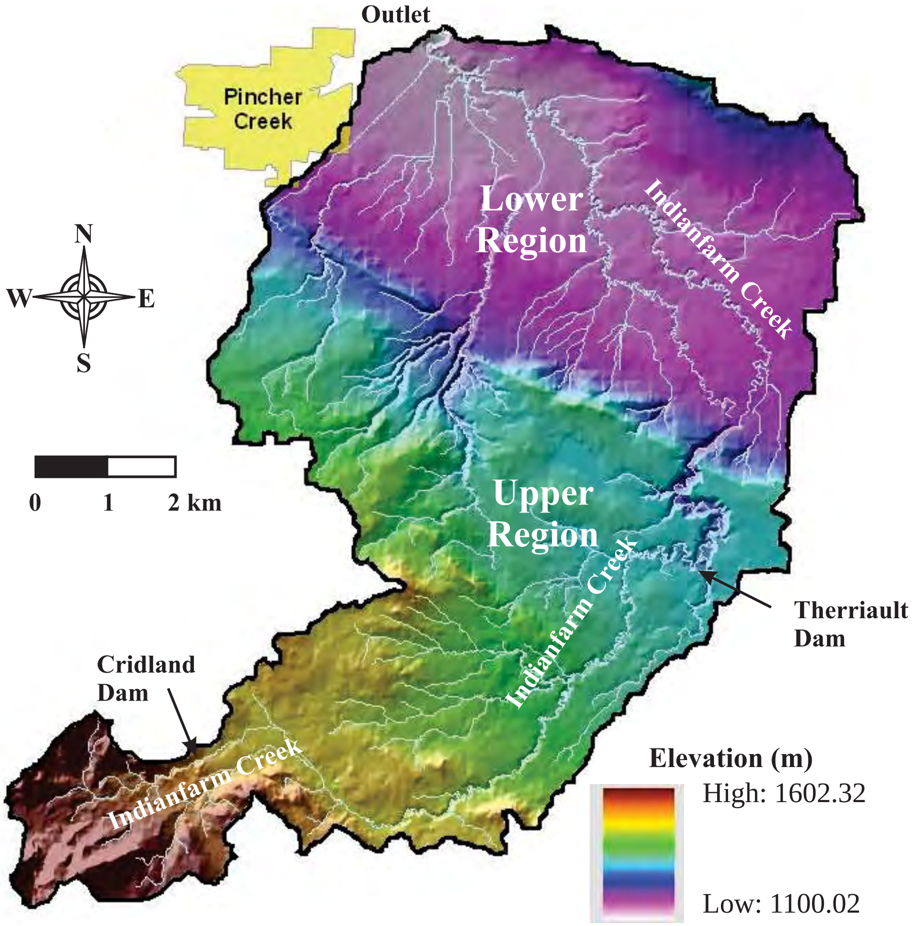


Figure 4.2. Surface topography of Indianfarm Creek Watershed.

Table 4.1. Annual total precipitation for Pincher Creek and annual flow at the outlet of Indianfarm Creek Watershed (Station 1) from 2007 to 2012.

Year	Total precipitation[z,y] (mm)	Annual flow ($m^3\ yr^{-1}$)	Event-based distribution of flow: Snowmelt (%)	Event-based distribution of flow: Rainfall/base flow[x] (%)
2007	339.2	813,791	32	68
2008	643.0	6,937,239	26	74
2009	560.5	3,684,749	10	90
2010	741.0	23,804,103	4	96
2011	564.3	23,157,841	43	57
2012	441.5	301,593	37	63
Average	548.3	9,783,219	25	75

[z] Precipitation from the Environment Canada Pincher Creek AUT weather station (ARD 2013a).
[y] The 30-year average for the Pincher Creek AUT weather station is 514.8 mm (ARD 2013a).
[x] Includes releases from Therriault Dam in 2008 and 2009.

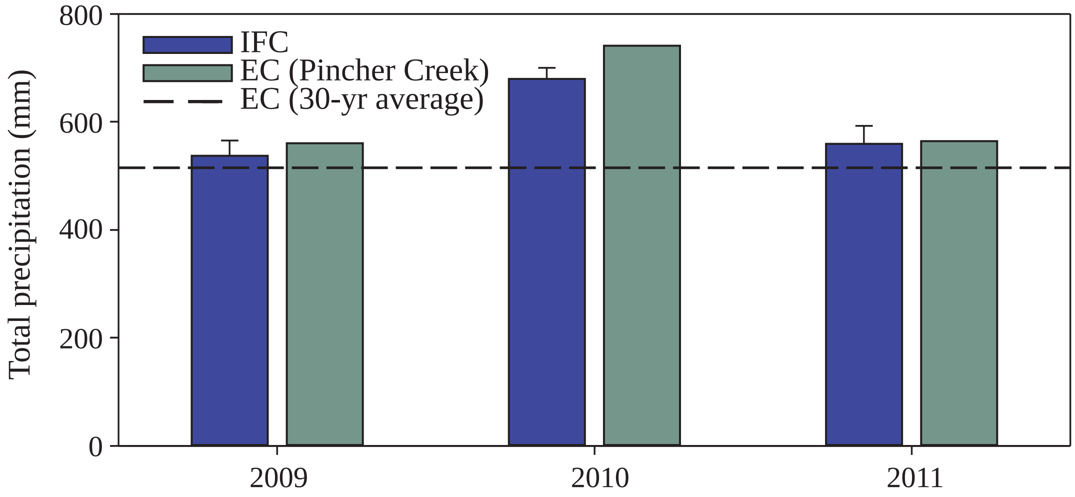


Figure 4.3. Average total precipitation of the four Indianfarm Creek weather stations and Environment Canada Pincher Creek weather station (2009 to 2011). T-bars for the Indianfarm Creek data are standard deviations.

4.3 Land Use

From 2007 to 2012, approximately 97% of the IFC Watershed was in agriculture production (Figure 4.4a). The major agricultural land uses in the IFC Watershed were annual crops (39%), perennial crops (56%), and farmyards (<2%). Other land uses included 1% natural areas (water bodies, wetlands, and grassed areas) and 3% non-agricultural areas (residential, idle land, and infrastructure).

Land use in the lower region (north) of the watershed was dominated by annual cropping (about 70% of the area) and included some livestock and one large feedlot. The upper region (south), which started in the Rocky Mountain Foothills, had about 75% of the area in pasture and hay land, about 25% annual cropping, and one medium-sized feedlot. Compared to the lower region, the upper region was more undulating progressing to rugged topography in the foothills. This topography limited the available arable land for annual crops and was more conducive to livestock grazing. Within the lower region, stream channels were fenced into very narrow bands of natural pastures for cattle grazing and surrounded by cropland. In the upper region, the narrowing of pasture land adjacent to stream channels was not as severe.

Livestock in the watershed (Figure 4.4b) included feedlots, beef and dairy cattle, horses, and sheep. About 34,500 head of cattle were estimated to be in the watershed, including cow-calf and feedlot operations.

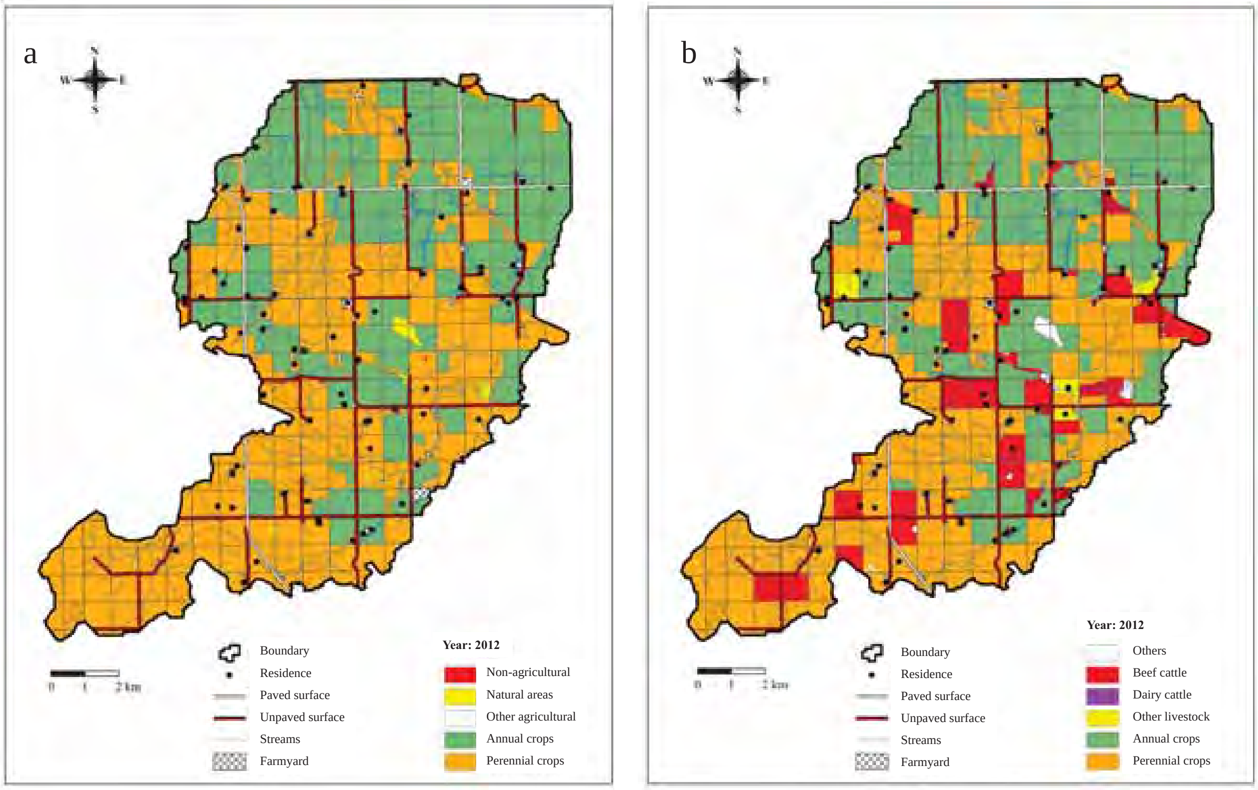


Figure 4.4. Land-use distribution for (a) annual crops and (b) livestock in Indianfarm Creek Watershed (2012).

The grazing cattle population was estimated at about 2500 animals based on an aerial survey in 2009. Stocking rate guidelines for the foothills rough-fescue region of Alberta (Adams et al. 2003) suggests that IFC Watershed could theoretically support about 2700 grazing cattle, given the area of the watershed in crop production. Therefore, the IFC Watershed, as a whole, was not overstocked at the time of the survey, assuming equal distribution of cattle throughout the pasture land. However, as noted, cattle were not evenly distributed and the cattle density along Indianfarm Creek and its tributaries has resulted in stream bank and riparian zone degradation, particularly in the lower region (Figure 4.5). Figure 4.6 provides aerial overviews of the upper (Figure 4.6a,b) and lower (Figure 4.6c,d) regions of the watershed. Tributaries of IFC in the lower region were often left as thin bands of grass or perennial forage surrounded by annual crops (Figure 4.6d).

The number of grazing cattle was more concentrated in the upper region of the watershed. Observations showed that cattle were winter fed in close proximity to feed sources or farmyards in early March. This is a common practice during calving season. The limited land available for livestock in the lower region was evident by the proximity of bedding and feeding areas near the IFC mainstem and tributary channels (Figure 4.5).

Figure 4.5. Example of a winter bedding and feeding site adjacent to Indianfarm Creek prior to BMP implementation.

Figure 4.6. Aerial images of Indianfarm Creek Watershed (2009).

4.4 Water Quality

The average concentration of TN and TP generally increased in IFC from the headwaters (Station 20) to the outlet (Station 1) for all event types (Figures 4.7 and 4.8). Total N values ranged from < 1 mg L^{-1} at headwaters to about 2 mg L^{-1} near the downstream outlet. Tributary TN values were generally higher than the mainstem, likely because of lower flows and therefore less dilution capability. Total P concentrations almost always exceeded the 0.05 mg L^{-1}, which was previously the guideline for protection of the aquatic environment.

Average TSS concentration patterns throughout the IFC Watershed (Figure 4.9) were similar to PP concentrations. Generally TSS concentration increased from upstream (Station 20) to downstream (Station 1) on the mainstem. Tributary stations had lower TSS concentrations than the downstream reach

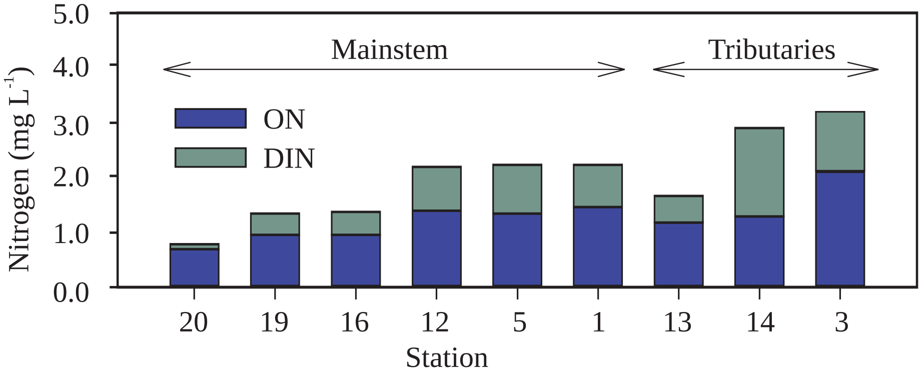


Figure 4.7. Average total nitrogen concentration shown as fractions of organic nitrogen (ON) and dissolved inorganic nitrogen (DIN). Averages are for all flow events from 2007 to 2012.

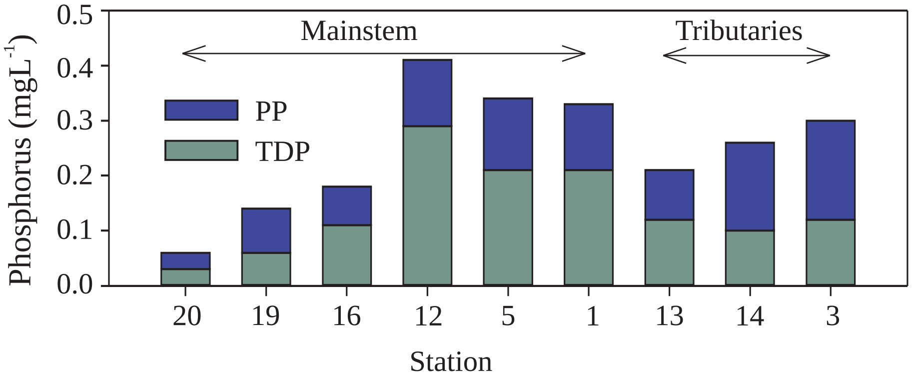


Figure 4.8. Average total phosphorus concentration shown as fractions of total dissolved phosphorus (TDP) and particulate phosphorus (PP). Averages are for all flow events from 2007 to 2012.

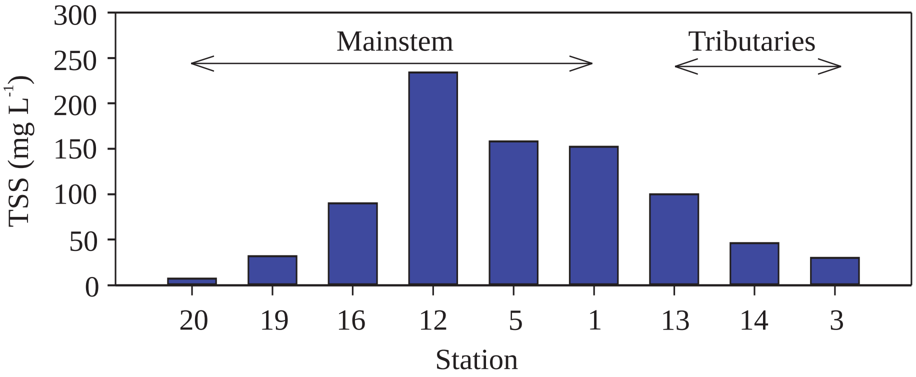


Figure 4.9. Average concentration of total suspended solids (TSS) for all flow events (2007 to 2012).

(Stations 12 to 1) of the mainstem, likely because of smaller flows and hence, less erosion in the tributaries compared to the mainstem.

Escherichia coli concentrations tended to reflect the season, with concentrations typically higher during the summer months. A similar trend was also observed in agricultural watersheds by Lorenz et al. (2008). Unlike the nutrient concentrations, there was no noticeable trend in *E. coli* concentrations from upstream to downstream in IFC (Figure 4.10).

The annual nutrient and TSS mass loads at the watershed outlet generally increased with annual flow (Table 4.2). Flow appears to be the primary driver for mass load differences among the low (2007, 2012), intermediate (2008, 2009), and high-flow (2010, 2011) years.

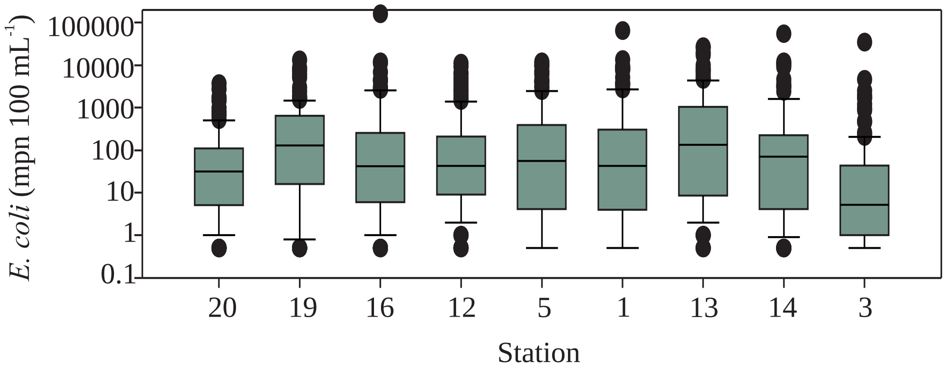


Figure 4.10. Box plots of *Escherichia coli* (*E. coli*) median, upper, and lower quartile; minimum and maximum (T-bars); and outlier (black dots) concentrations for all events for the watershed-wide stations (2007 to 2012).

Table 4.2. Annual mass load of nutrients and total suspended solids and flow at the outlet (Station 1) from 2007 to 2012.

Variable	**2007^{z}**	**2008^{y}**	**2009^{x}**	**2010^{w}**	**2011^{v}**	**2012^{u}**
TN (kg yr^{-1})	1,352	28,337	5,414	129,913	148,781	645
ON (kg yr^{-1})	1,088	24,783	4,722	64,688	51,164	396
DIN (kg yr^{-1})	263	3,554	691	65,225	97,617	249
TP (kg yr^{-1})	149	6,390	601	36,646	23,237	66
TDP (kg yr^{-1})	54	698	202	9,602	9,265	29
PP (kg yr^{-1})	95	5,963	399	27,044	13,972	37
TSS (kg yr^{-1})	60,038	6,493,098	248,627	21,769,529	11,238,750	12,952
Flow (m^{3} yr^{-1})	813,791	6,937,239	3,684,745	23,804,103	23,157,841	301,593

[z] Loads calculated from February 22 to June 19.

[y] Loads calculated from February 17 to November 18.

[x] Loads calculated from March 24 to December 1.

[w] Loads re-calculated from February 10 to December 31. Flows were re-adjusted for 2010 and these values were different than values reported in Olson and Kalischuk (2011).

[v] Loads calculated from January 28 to October 28.

[u] Loads calculated from March 5 to June 30.

4.5 Beneficial Management Practices Sites

Twelve BMP sites were established in the IFC Watershed (Figures 4.11 and 4.12). At the start of the study in 2007, seven BMP sites were established and these included the Impoundment (IMP), North Manure Field (NMF), Pasture (PST), Wintering (WIN), South Manure Field (SMF), Dairy Manure Field (DMF), and Reference (REF) sites. Five additional sites were established in 2010 and these included the Fencing (FEN), Catchment (CAT), Feedlot (FLT), Off-stream Watering (OSW), and Dugout (DUG) sites.

Most of the BMP sites were in the lower region of the watershed. Of the 12 BMP

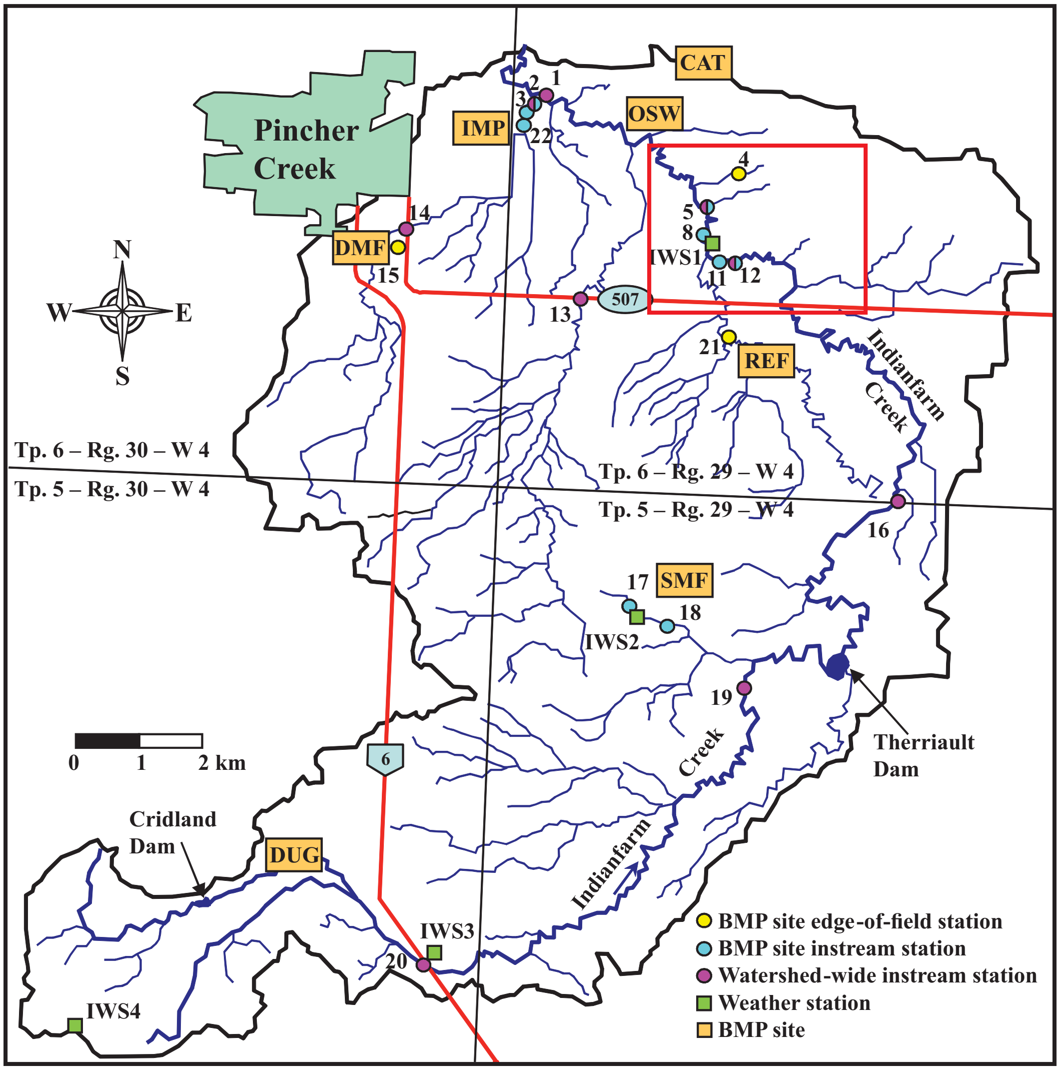


Figure 4.11. Location of the Indianfarm Creek Watershed beneficial management practices sites and water monitoring stations.

sites, eight sites focused on cattle management (DUG, FLT, IMP, NMF, OSW, PST, REF, and WIN). Two sites (CAT and FLT) focused on surface-water management. The remaining two sites focused on manure nutrient management (DMF and SMF).

Of the 12 BMP sites selected in IFC Watershed (Figure 4.13; Table 4.3), BMP plans were successfully implemented at nine sites. Beneficial management practices plans could not be implemented at the SMF site, or maintained at the DMF and REF sites. The main goals of the BMPs were to:

- Reduce cattle access to IFC, its tributaries, and drainage channels leading to the creek and tributaries;
- Manage surface runoff at feedlots to protect fresh runoff from being contaminated by feedlot runoff; and
- Manage manure from intensive livestock and cow-calf operations to reduce nutrient leaching and runoff.

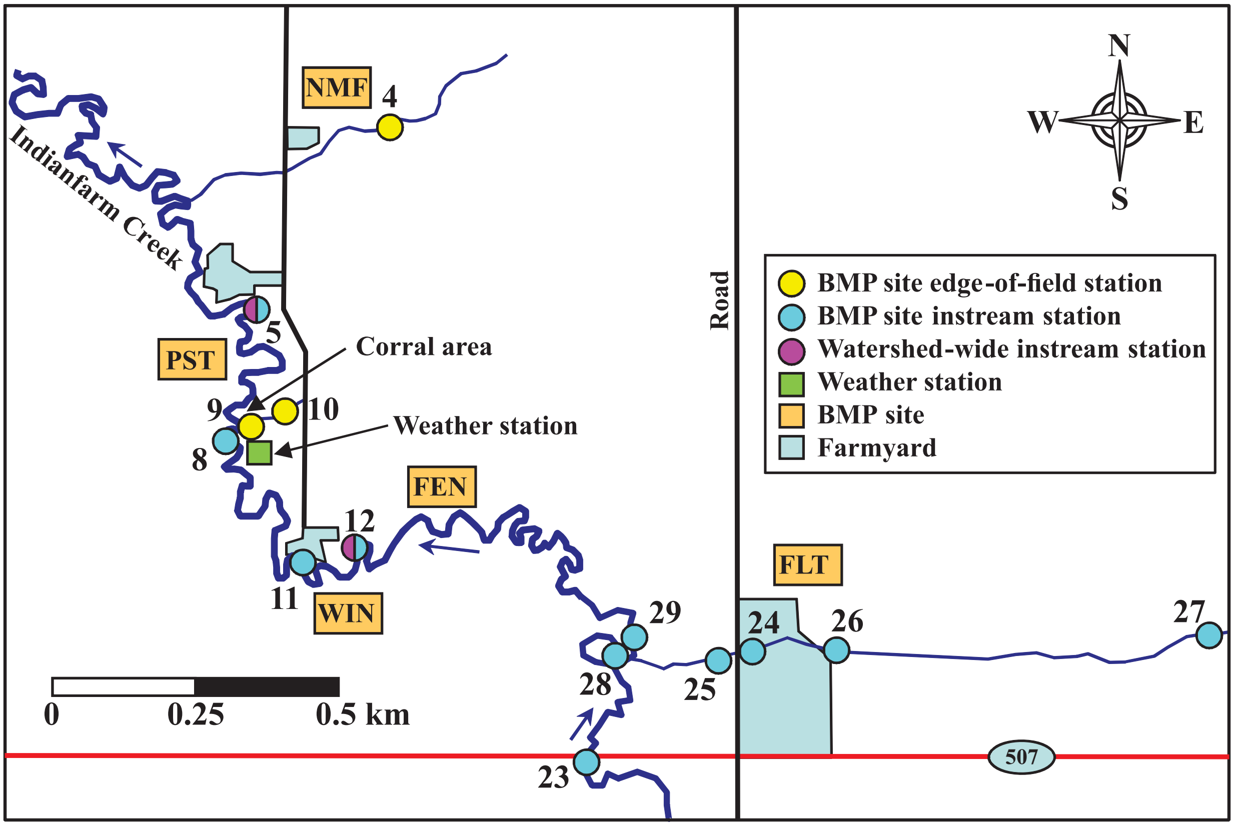


Figure 4.12. More detailed view of beneficial management practices sites and water monitoring stations in Figure 4.11 (red box).

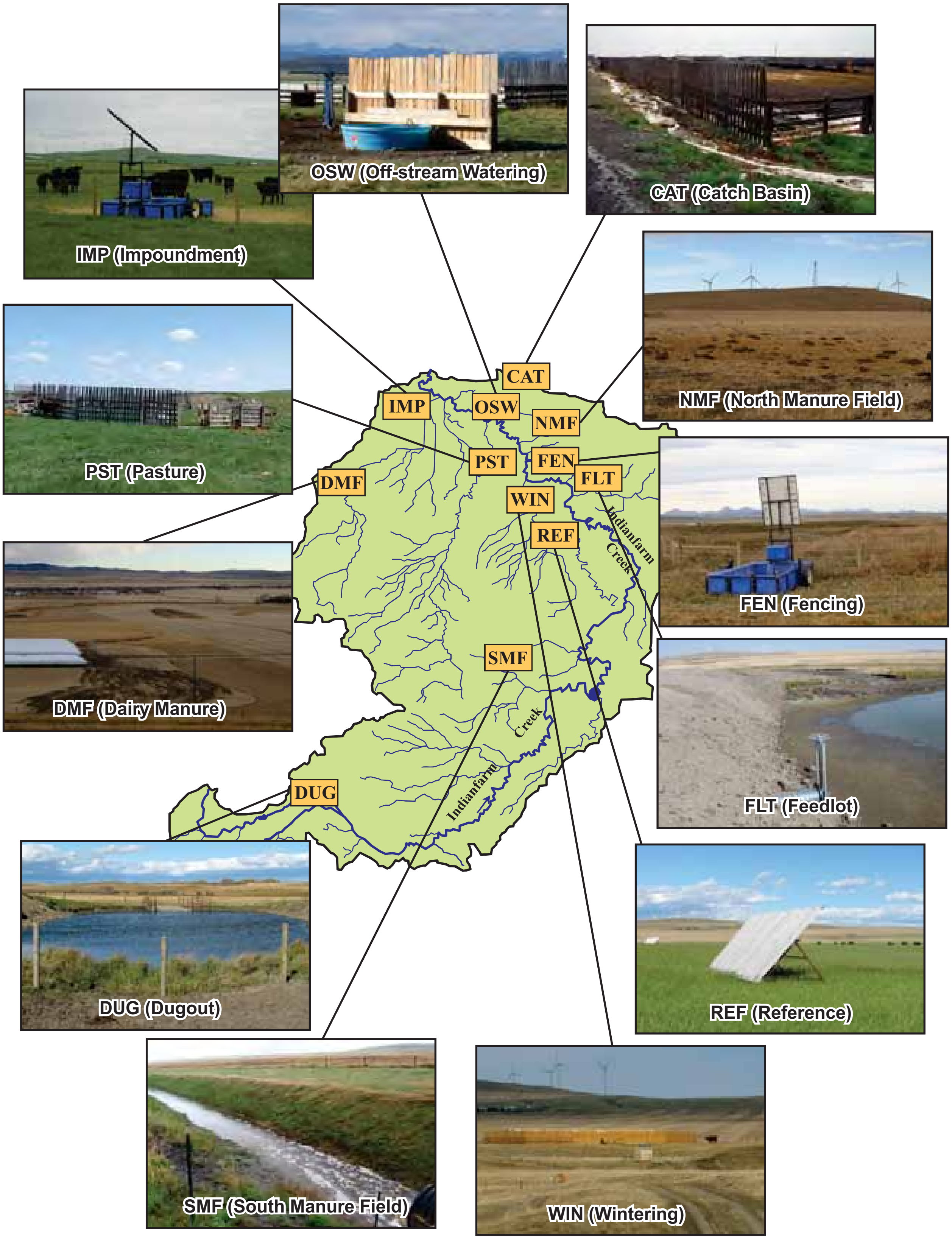


Figure 4.13. Overview of beneficial management practices sites.

Table 4.3. A description of issues and beneficial management practices (BMPs) plans for the Indianfarm Creek Watershed BMP sites.

Site[z]	Type[y]	Issues	BMP plan
IMP	C	• Direct access by cattle to a main tributary • Riparian area degraded	• Cattle exclusion and distribution control using fencing, off-stream watering, and portable windbreak
WIN	C	• Direct access by cattle to the creek • Stream bank and riparian area degraded • Winter feeding area next to the creek	• Rotational grazing and off-stream watering to protect riparian area during sensitive periods • Wintering site relocated • Bioengineering
PST	C	• Direct access by cattle to water • Over grazed pasture • Corrals and manure pack next to the creek • Stream bank and riparian area degraded	• Rotational grazing and off-stream watering to protect riparian area during sensitive periods • Corral removal and relocation • Bioengineering
DMF	N	• High rates of manure applied • Moderately high P in surface soil • Lack of capacity for long-term (6 to 9 mo) manure storage	• BMP plan was not successfully implemented
NMF	C	• Fall grazing of cattle affected a grass drainage channel in field with a concentration of fecal pats	• Cattle distribution control during fall grazing • Excluded cattle from drainage channel with temporary electric fence
SMF	N	• Field slope towards a drainage channel • Manure applied and exposed on surface • Fall grazing and access to drainage channel	• BMP plan not successfully implemented
REF	C	• Cattle access to an in-field drainage channel during fall grazing	• Cattle distribution control during fall grazing including electric fencing • Crop residue management
DUG	C	• Direct access by cattle to dugouts and to Indianfarm Creek within a pasture • Riparian degradation	• Control access of cattle to dugouts with fencing • Off-stream watering • Improved cattle crossing with a bridge
OSW	C	• Direct access by cattle to a dugout and creek • Riparian degradation	• Excluded cattle from dugout • Off-stream watering
FLT	C,S	• Cattle feeding and bedding area alongside a tributary • Highly degraded riparian area • Flooding of feedlot catch basin and dugout	• Relocation of bedding and feeding site • Re-direct tributary flow, grass waterway • Improve berms around dugout and catch basin
FEN	C	• Direct access by cattle to the creek during fall grazing of an adjacent field	• Prevent access to creek with fencing • Off-stream watering
CAT	S	• Excessive run-on through feedlot during heavy precipitation was not contained and entered the creek	• Drainage ditch was constructed to divert run-on away from the feedlot

[z] IMP = Impoundment, WIN = Wintering, PST = Pasture, DMF = Dairy Manure Field, NMF = North Manure Field, SMF = South Manure Field, REF = Reference, DUG = Dugout, OSW, Off-stream Watering, FLT = Feedlot, FEN = Fencing, and CAT = Catch Basin.

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

Figure 4.14 shows examples of tools that were used to keep cattle away from surface water. Fencing was also used to control cattle access to water, including IFC, tributaries, and dugouts (Figure 4.15).

Manure management was the third major category of BMP implemented, and was designed to reduce runoff of nutrients and bacteria from excess manure on fields through spreading, stockpiling, or cattle feeding (Figure 4.16).

The cost of BMPs implemented in the IFC Watershed ranged from about $800 to nearly $88,000 (Table 4.4).

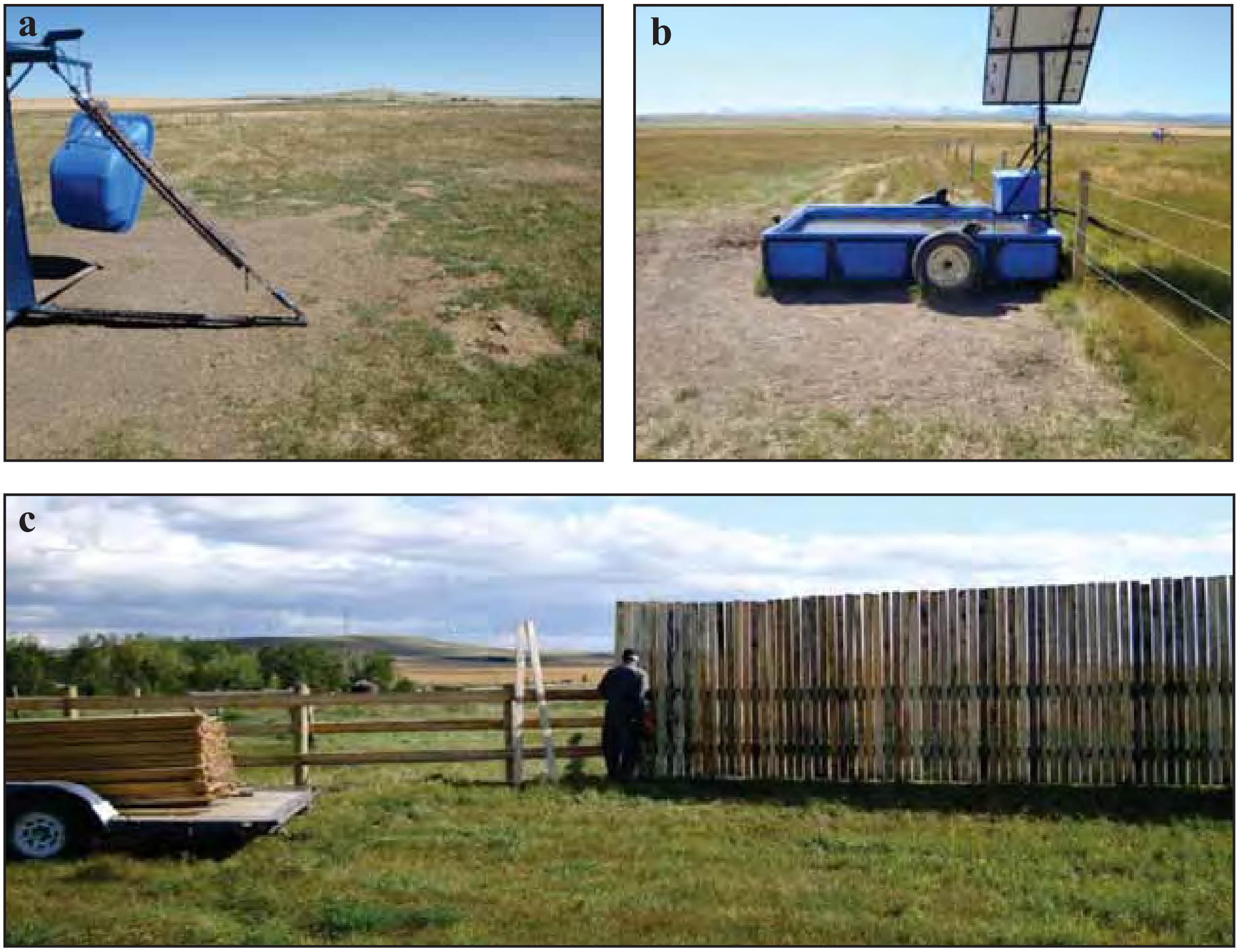


Figure 4.14. Images showing (a) cattle oiler, (b) solar powered off-stream watering systems, and (c) wind fence.

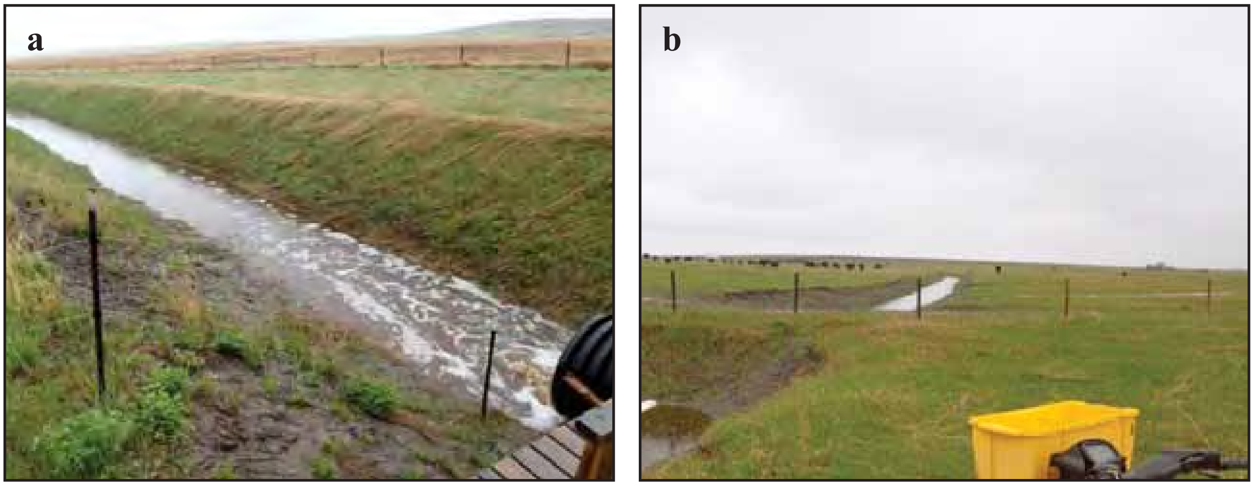


Figure 4.15. Fencing of stream and tributaries to regulate cattle access to water.

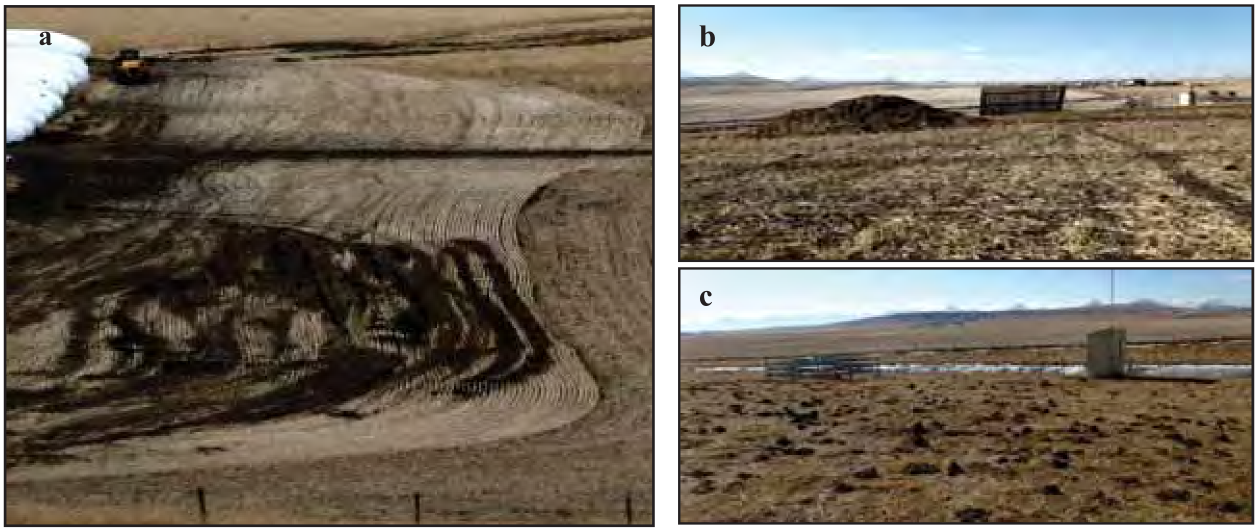


Figure 4.16. Images of (a) manure application, (b) manure stockpiling, and (c) manure pats from cattle feeding.

Table 4.4. Total cost of beneficial management practices at sites in the Indianfarm Creek Watershed.

Site[z]	Cost ($)	Labour (hours)
IMP	17,937	32
NMF	822	8
FEN	10,989	29
PST	16,643	148
PST - Bioengineering[y]	23,516	202
WIN	15,490	61
WIN - Bioengineering[y]	12,958	21
REF	2,766	13
OSW	4,641	15
DUG	8,026	63
FLT	87,770	96
CAT	13,200	32

[z] There were no BMP costs at the DMF and SMF sites.

[y] The cost of the bioengineering was separated from the implemented BMPs at the PST and WIN sites.

5 WHELP CREEK SUB-WATERSHED

5.1 Introduction

The WHC Sub-watershed is in the Central Parkland Natural Sub-region, approximately 6 km west of the Town of Lacombe (Figure 5.1). Its total drainage area is about 5000 ha. The 30-year average (1971 to 2000) annual precipitation is 446 mm (Environment Canada 2009). The annual runoff for the WHC Sub-watershed is estimated to be approximately 38 mm (Bell 1994). The watershed is in the Black Soil Zone (Alberta Soil Information Centre 2013) and the soils are generally a medium textured loam or silty loam.

The topography in the WHC Sub-watershed is undulating with high-relief landforms (Figure 5.2). The sub-watershed slopes downward from west to east, with an approximate 90-m difference in elevation between the lowest and highest points.

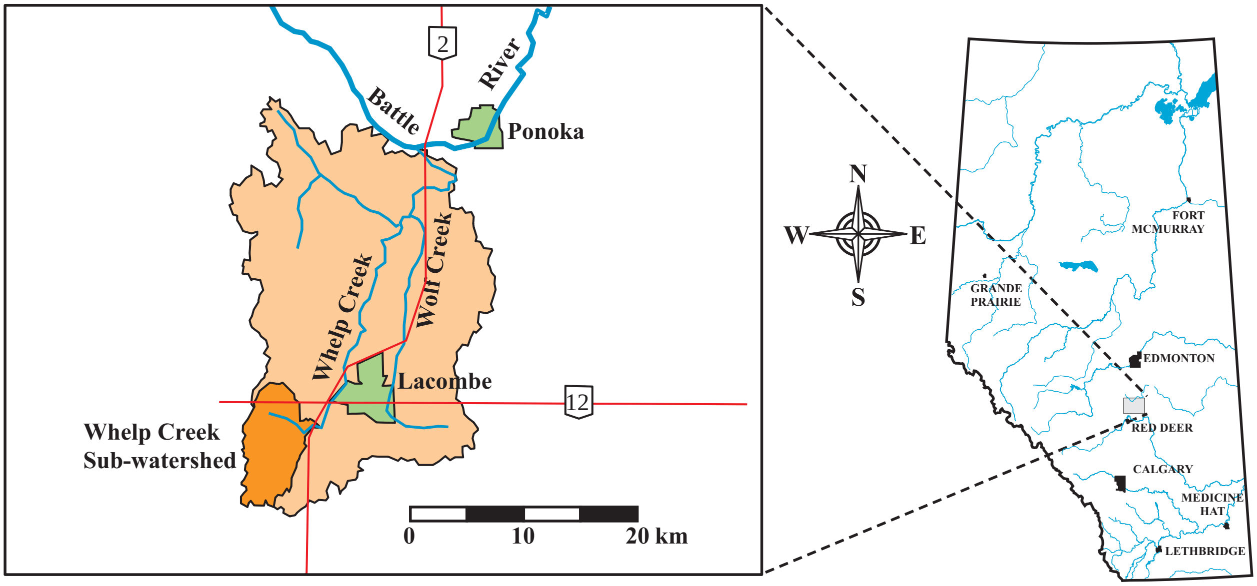


Figure 5.1. Location of the Whelp Creek Sub-watershed.

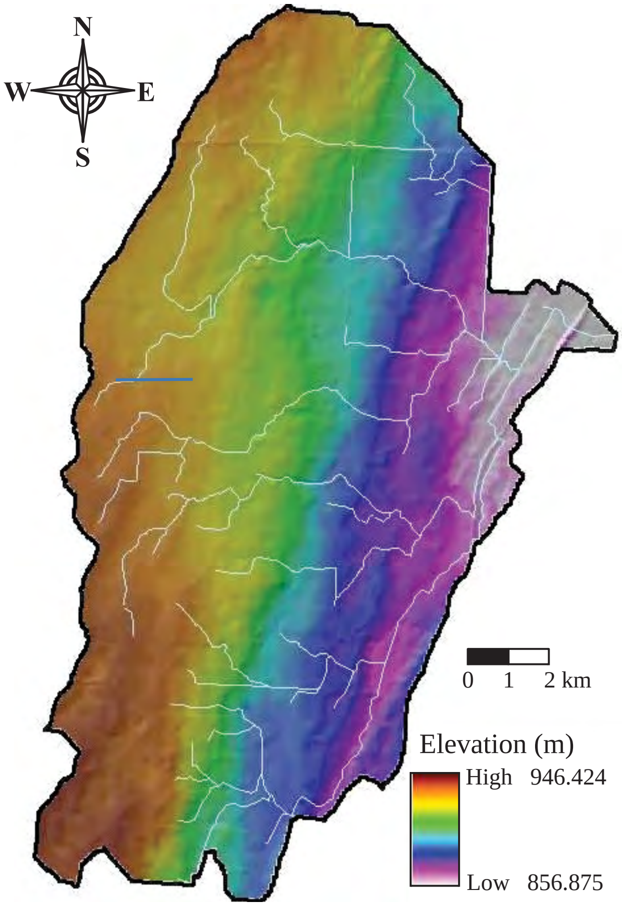


Figure 5.2. Topography and elevation of Whelp Creek Sub-watershed.

5.2 Surface Hydrology and Weather

Whelp Creek (also known as Whelp Brook) flows from the northwest corner of the sub-watershed in a southerly direction, then turns and flows east until it is joined by the southern tributaries. The creek then crosses under Highway 2 and flows north for about 30 km where it eventually discharges into Wolf Creek, which flows into the Battle River near Ponoka, Alberta (Figure 5.1).

Flow in the creek and its tributaries is influenced by a shallow water table in the area. There are several sloughs and other wetlands that dot the landscape in the sub-watershed. The stream beds in the sub-watershed are usually undefined and shallow (Figure 5.3a). These characteristics, combined with the variability of the weather, enable producers to often cultivate through portions of the creek and tributaries (Figure 5.3b).

Annual flow from the WHC Sub-watershed averaged about 1.72 million m^3 from 2009 to 2012, but varied from year to year. The combined annual flow of the tributary

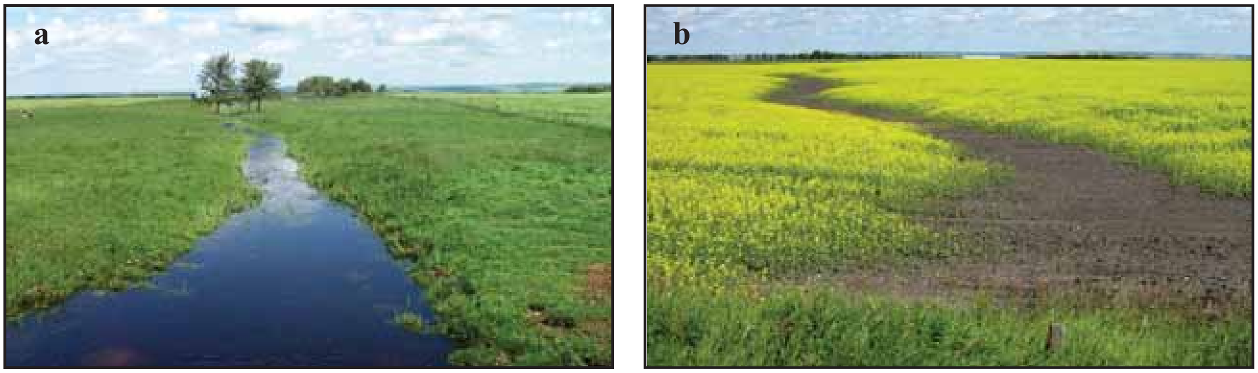


Figure 5.3. Views of (a) Whelp Creek and (b) a farmed-through tributary.

stations represented 23 to 47% of the total annual flow. Table 5.1 shows the annual flows of WHC at the outlet relative to total precipitation. Flow and precipitation were higher during the post-BMP period (2010 to 2012) compared to the pre-BMP period (2008 to 2009). On average, 45% of annual flow occurred during snowmelt events at the outlet of the sub-watershed. Flow typically began in April at the outlet and continued into the spring and/or summer.

Growing season temperature from 2007 to 2012 for the sub-watershed was about 13.1°C, which was slightly higher than the 30-year average of 12.8 °C. Figure 5.4 shows the annual precipitation for the WHC Sub-watershed, relative to the long-term average for the area.

Table 5.1. Annual total precipitation and annual flow at the outlet of Whelp Creek Sub-watershed (2008 to 2012).

Year	Total precipitation^{z,y} (mm)	Annual flow ($m^3\ yr^{-1}$)	Event-based distribution of flow	
			Snowmelt	Rainfall/base flow
			------------- (%)	-------------
2008	288.5	355,999	42	58
2009	295.1	25,319	100	0
2010	531.8	644,966	0	100
2011	495.6	5,896,213	46	54
2012	395.7	1,686,658	39	61
Average	401.3	1,721,831	45	55

[z] Precipitation at the Lacombe CDA2 weather station (ARD 2013a).
[y] The 30-year average for the Lacombe CDA2 weather station is 446.0 mm (ARD 2013a).

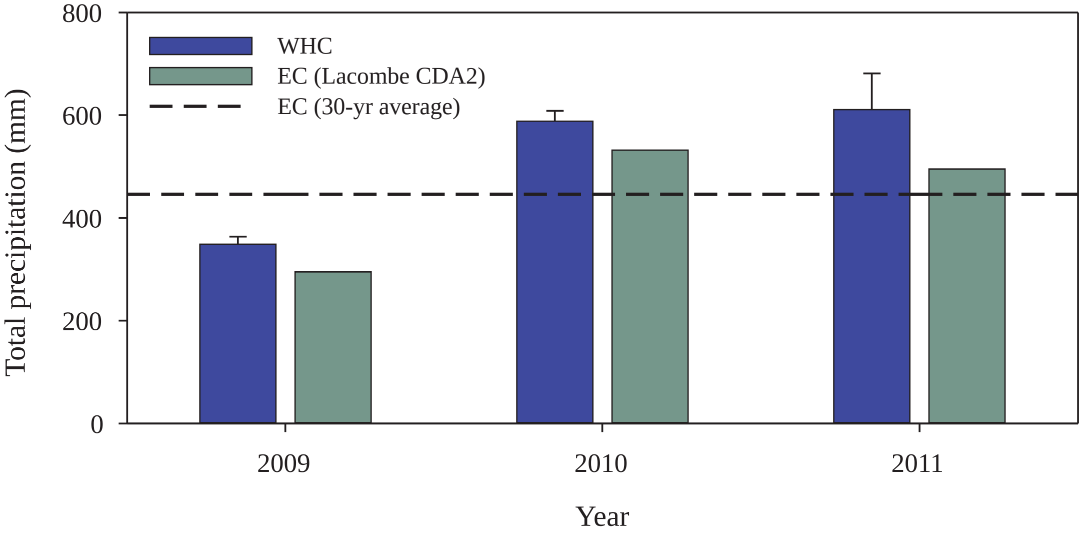


Figure 5.4. Average total precipitation of the Whelp Creek Sub-watershed weather stations compared to the Environment Canada Lacombe CDA2 weather station (2009 to 2011). T-bars for the Whelp Creek data are standard deviations.

5.3 Land Use

The total area of the WHC Sub-watershed is about 5000 ha, and in 2007, included approximately 60 landowners with 50 active producers. Agricultural land accounted for approximately 87% of the sub-watershed and included annual crops (62.3%) and perennial crops (22.7%), and farmyards (1.6%). Natural areas (forest, grassland, water bodies, and wetlands) comprised about 9.2% of the sub-watershed. The major annual crops included barley (24.1%), canola (20.3%), wheat (11.2%), corn (4.0%), and potato (1.0%) (Figure 5.5a). Perennial crops (pasture and hay) accounted for about 23% of the area (Figure 5.5a).

The WHC Sub-watershed had significant livestock production, which was dominated by confined feeding operations, including dairies and to a lesser extent beef feedlots (Figure 5.5b). There were about 2200 cows and 500 calves in the sub-watershed. There were also three hog operations active in the watershed, but these went out of business by 2009.

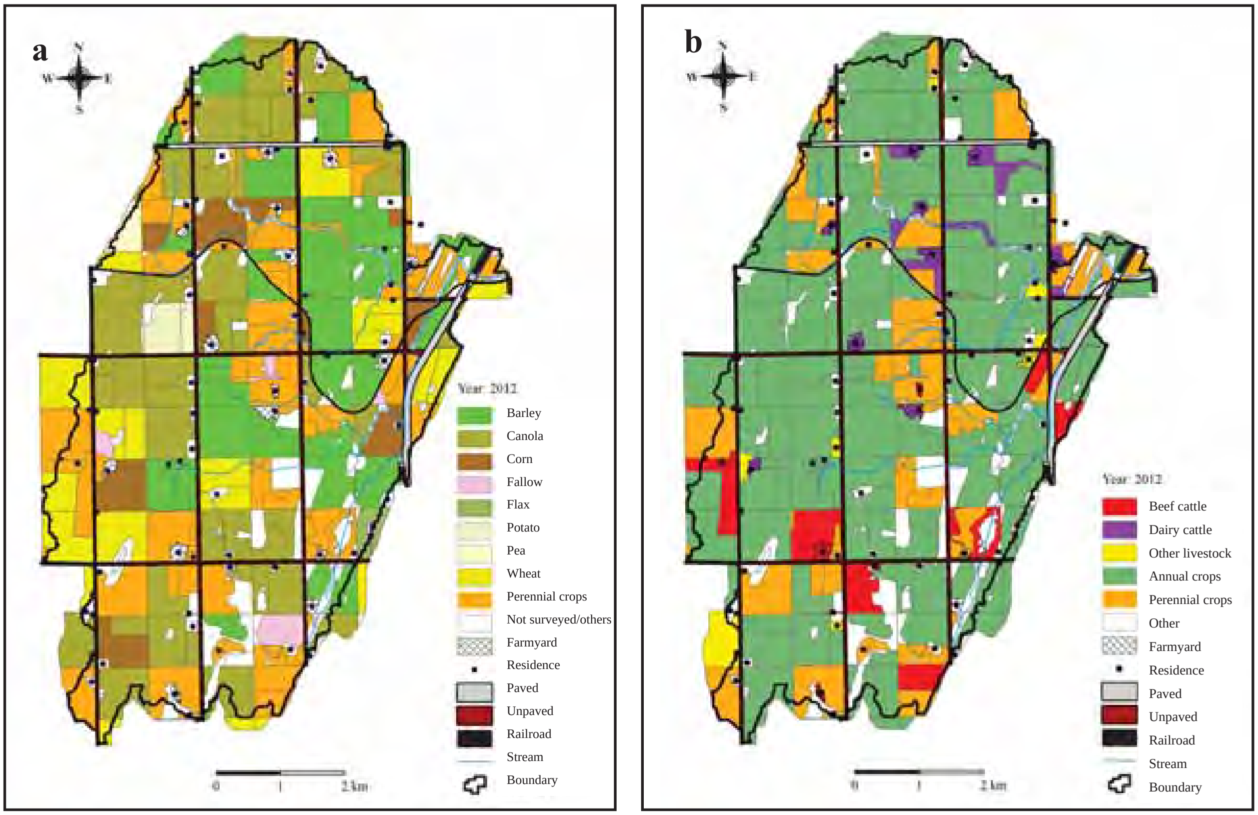


Figure 5.5. Land-use distribution of (a) annual crops and (b) livestock in the Whelp Creek Sub-watershed (2012).

5.4 Surface Water Quality

For the mainstem, the average concentration of TN and TP decreased from upstream to downstream (Figures 5.6 and 5.7). Total N was dominated by ON at most of the watershed-wide stations and TP was dominated by TDP at all of the stations. The average concentration of TSS in WHC increased from upstream to downstream (Figure 5.8).

The concentrations of TN and TP were higher during snowmelt than rainfall runoff throughout the watershed. The average TN concentration consisted of 77% ON, with 61% during snowmelt and 92% during rainfall. These proportions were similar for the IFC Watershed. On average, 88% of TP was in dissolved form (TDP) at the outlet of the WHC Sub-watershed, and similar proportions were observed for snowmelt and rainfall events. This was in contrast to the IFC Watershed, which only had 37% of TP in the form of TDP at the outlet. The IFC Watershed was more erosive due to greater elevation difference, incised channels, and flashier runoff events. There was no clear trend among parameter concentrations with respect to year, and essentially no relationship between flow and concentration of water quality parameters.

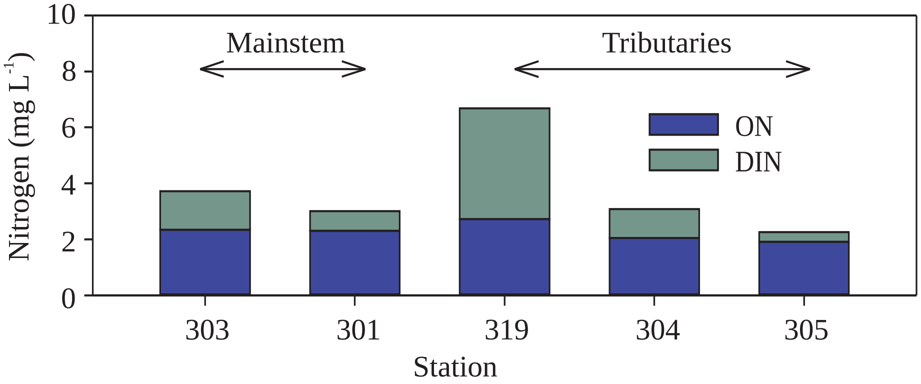


Figure 5.6. Average total nitrogen concentration shown as fractions of organic nitrogen (ON) and dissolved inorganic nitrogen (DIN). Averages are for all flow events from 2008 to 2012.

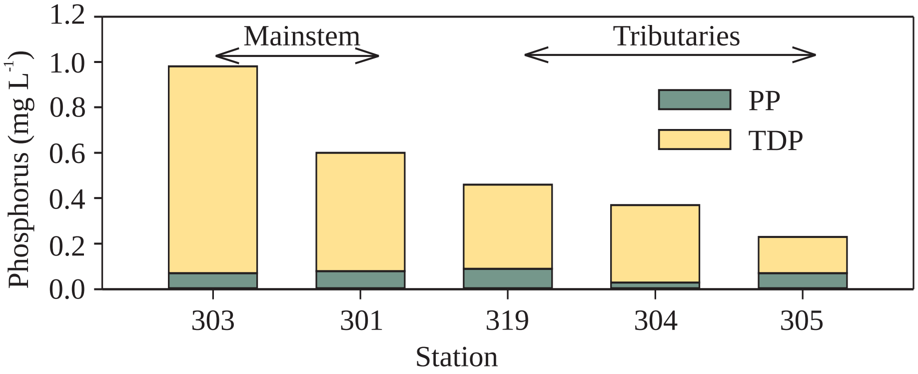


Figure 5.7. Average total phosphorus concentration shown as fractions of total dissolved phosphorus (TDP) and particulate phosphorus (PP). Averages are for all flow events from 2007 to 2012.

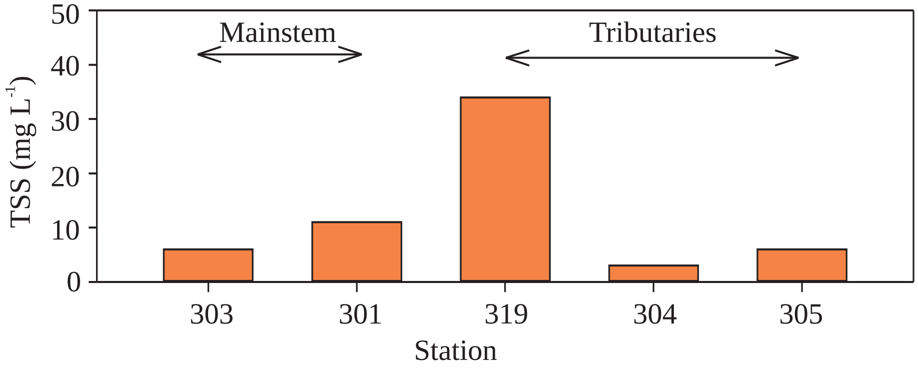


Figure 5.8. Average concentrations of total suspended solids (TSS) for all runoff events (2008 to 2012).

For all events combined, median concentration of *E. coli* was higher at Stations 303 (39 mpn 100 mL^{-1}) and 301 (40 mpn 100 mL^{-1}) compared to the three tributary stations (7 to 24 mpn 100 mL^{-1}) (Figure 5.9). The slight reduction in concentration from Station 303 to Station 301 may have been caused by a dilution effect by the tributaries. Lower concentration of *E. coli* during snowmelt periods were observed, and this is typical for other agricultural watersheds in Alberta (Lorenz et al. 2008). This is likely related to colder temperature causing less microbial activity in the early spring compared to rainfall conditions in the late spring and summer.

Annual nutrient and sediment mass loads increased with annual flow at the outlet of the sub-watershed (Table 5.2). Regression analysis showed a strong relationship ($r^2 > 0.97$; $P < 0.002$) between all parameter mass loads and flow.

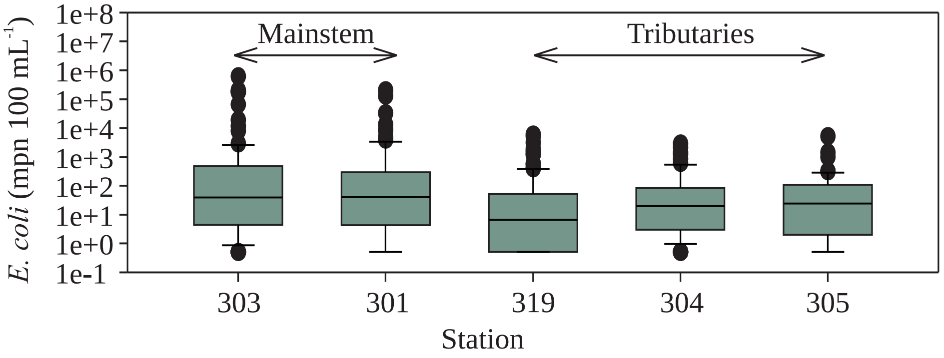


Figure 5.9. Box plots of *Escherichia coli* (*E. coli*) median, upper, and lower quartile; minimum and maximum (T-bars); and outlier (black dots) concentrations for all events for the watershed-wide stations (2008 to 2012).

Table 5.2. Annual mass load of nutrients, total suspended solids, and annual flow at the Whelp Creek Sub-watershed (2008 to 2012).

Variable[z]	**2008**[y]	**2009**[x]	**2010**[w]	**2011**[v]	**2012**[u]
TP (kg yr^{-1})	168	17	655	5,522	860
TDP (kg yr^{-1})	144	15	585	4,924	724
PP (kg yr^{-1})	24	2	70	598	136
TN (kg yr^{-1})	1,173	94	1,523	25,432	5,997
ON (kg yr^{-1})	969	58	1,288	12,895	3781
DIN (kg yr^{-1})	204	36	235	12,615	1869
TSS (kg yr^{-1})	3,122	74	7,976	95,831	22,398
Flow (m^3 yr^{-1})	355,999	25,319	644,966	5,896,213	1,686,658

[z] TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TN = total nitrogen, ON = organic nitrogen, DIN = dissolved inorganic nitrogen (NO_3-N plus NH_3-N), TSS = total suspended solids.
[y] Loads calculated from March 21 to July 12.
[x] Loads calculated from April 6 to 28.
[w] Loads calculated from May 21 to October 3.
[v] Loads calculated from April 6 to September 28.
[u] Loads calculated from March 19 to June 30.

5.5 Groundwater Hydrology and Quality

A groundwater investigation in the WHC Sub-watershed was initiated in 2009 as groundwater appeared to be a potential contributor to surface-water flow. The goal of the groundwater work was to understand the physical and chemical characteristics of the shallow groundwater regime in the WHC Sub-watershed.

5.5.1 Well Instrumentation

Monitoring wells were installed in and around the WHC Sub-watershed from August to December 2009. Groundwater monitoring nests were installed within the WHC Sub-watershed and east between the sub-watershed and Lacombe Lake (Figure 5.10). Groundwater nests were installed using a hydraulic coring unit (Figure 5.11a). The majority of nests included one water

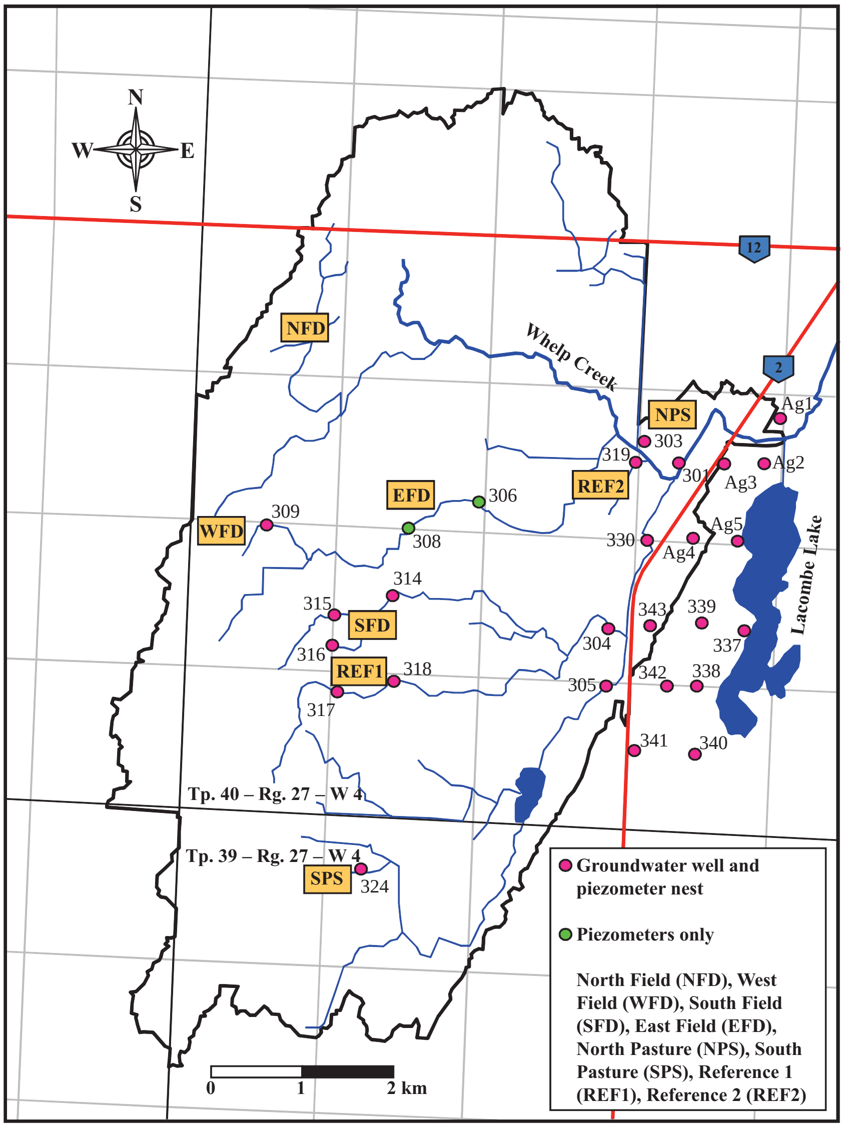


Figure 5.10. The Whelp Creek Sub-Watershed showing the locations of beneficial management practices sites and the locations of groundwater well and piezometer nests.

table well and two piezometers (Figure 5.12). The depths of water table wells ranged from 3.5 to 4.0 m below ground surface (bgs), while the piezometers ranged from 4.5 to 17.0 m bgs.

5.5.2 Groundwater Monitoring, Soil Sampling, and Data Analysis

Water levels were recorded using a water-level meter with depth sounder (Solinst model 102, Canada). Continuous water-level

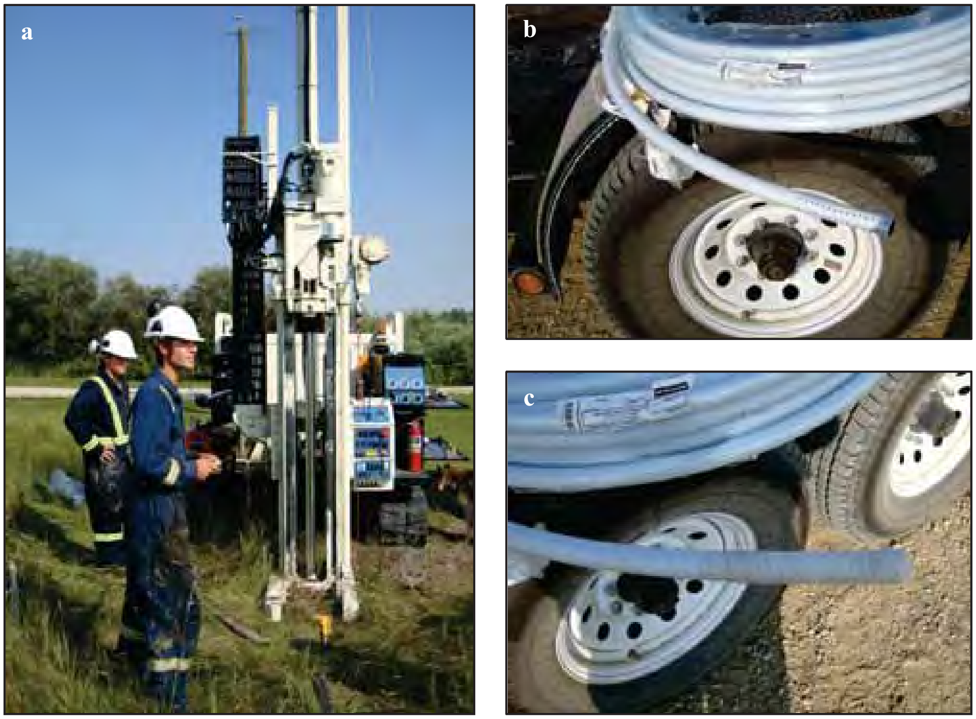


Figure 5.11. Installation of groundwater wells and piezometers.

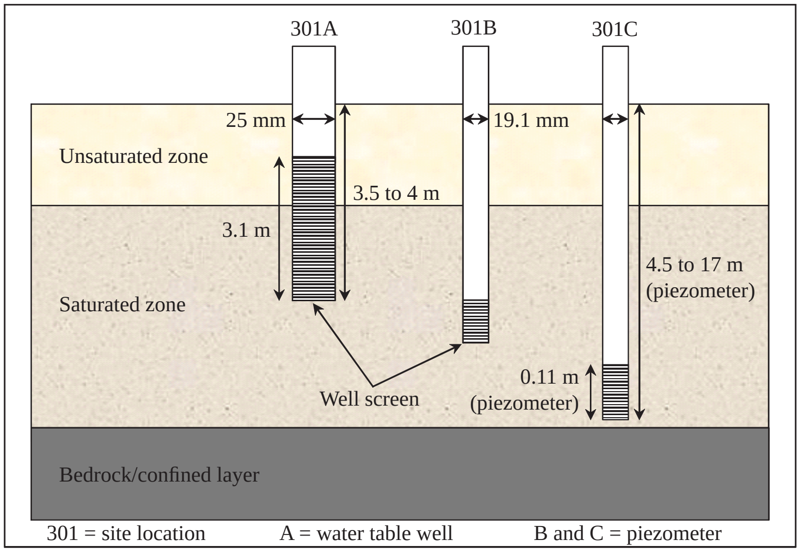


Figure 5.12. Schematic of water table well and piezometers at a typical nest site.

measurements were obtained in the water table well at the outlet (Well 301A) of the sub-watershed using a Level TROLL® (in-Situ Inc., Fort Collins, Colorado, United States) (Figure 5.13).

Contour plots used to illustrate horizontal groundwater flow direction were prepared with grids generated using the Kriging method of interpolation.

Water-level measurements from all water table wells were used to determine groundwater flow directions, while only data from water table wells within the WHC Sub-watershed were used to compare groundwater and surface water quality. Groundwater data were also compared to drinking water quality guidelines for NO_3-N and to aesthetic objectives for Cl (Health Canada 2012).

Vertical hydraulic gradients were calculated for adjacent wells in each nest using water-level measurements for representative dates in 2010. Hydrograph analysis was conducted to estimate the proportion groundwater discharge to the total flow at the sub-watershed outlet.

Groundwater samples were collected from 2010 to 2012 and analyzed for NO_3-N, Cl, NH_3-N, TN, TDP, TP, total coliforms (2010 only), and *E. coli* (2010 only).

Deep-core soil samples were collected at six sites (EFD, NFD, SFD, WFD, REF1, and REF2) to determine nutrient leaching. Soil cores were collected in 0.3-m incremental layers to a maximum depth of 3 m in 2009 and 2010. Samples were analyzed for extractable NO_3-N, NH_4-N, STP, and Cl.

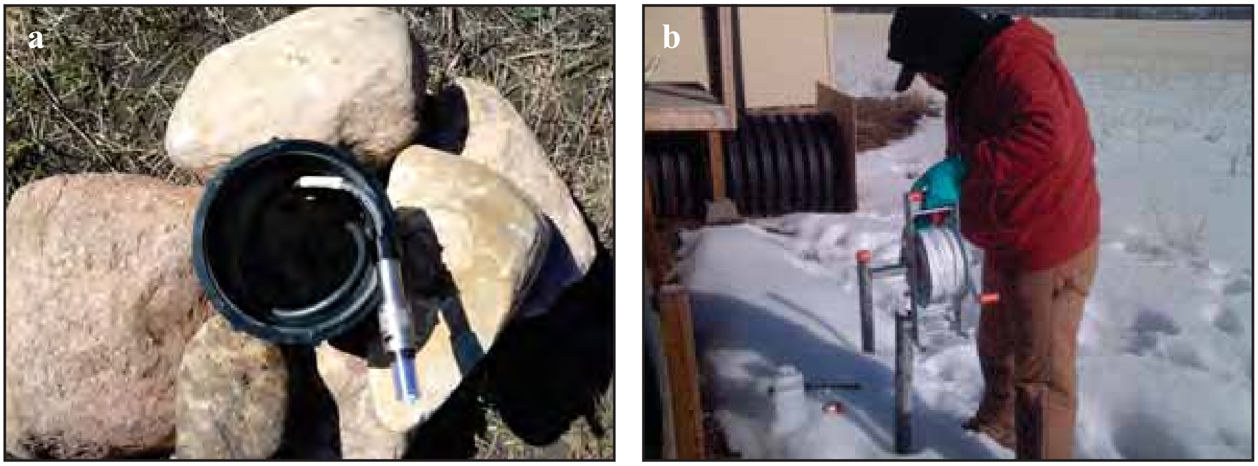


Figure 5.13. Measuring groundwater level with (a) Level TROLL and (b) a water level meter with depth sounder.

5.5.3 Groundwater Levels and Quality and Soil Nutrient Profiles

Monitoring showed that shallow groundwater moved from west to east across the WHC Sub-watershed. Groundwater levels in the water table wells ranged from 0.03 to 4.12 m bgs, with annual averages ranging from 1.16 m bgs in 2011 to 2.20 m bgs in 2010. Groundwater discharge to stream flow was estimated to contribute 48% of total annual flow at the sub-watershed outlet on average from 2010 to 2012.

Shallow groundwater NO_3-N and Cl concentrations measured within the WHC Sub-watershed generally did not change seasonally, and did not exceed Canadian Drinking Water Quality Guidelines (Health Canada 2012). Groundwater NO_3-N and Cl concentrations were generally similar to or lower than those measured in surface water within the sub-watershed. Groundwater concentrations of NO_3-N and Cl near the outlet generally did not contribute to the elevated surface water concentrations measured during the summer months. Groundwater discharge to the ground surface likely caused a dilution effect or just prolonged surface flows with lower concentrations.

At two of six sites, there was evidence of NO_3-N and Cl leaching in the soil profile to a depth of 1.5 to 2 m. The likely source of the NO_3-N and Cl was from manure application.

5.6 Beneficial Management Practices Sites

Eight BMP sites were established in the WHC Sub-watershed in 2008 (Figures 5.14 and 5.15; Table 5.3). These included the West Field (WFD), North Field (NFD), East Field (EFD), South Field (SFD), North Pasture (NPS), and South Pasture (SPS) sites. In addition, two Reference (REF1 and REF2) sites were established for comparison purposes.

Pasture and cattle management BMPs were the focus of the NPS and SPS sites, while manure nutrient management was the focus at the WFD, NFD, EFD, and SFD sites (Figure 5.14). For example, at the NFD site, dairy manure application was switched from surface application to injection (Figure 5.16a) and a manure storage area was moved further away from the creek (5.16b). At the SPS site, rotational grazing was adopted (Figure 5.16c). The effectiveness of the BMPs was assessed using water quality data at five of the sites (WFD, NFD, SFD, NPS, and SPS) and rangeland production assessment was used at the two pasture sites.

The cost of BMPs ranged from about $450 to nearly $6,000 (Table 5.4). Costs were generally lower than compared to the IFC Watershed and much less than compared to the BDF and LLB sites. Soil nutrient concentration (e.g., STP) was only moderately high at the WHC sites, meaning that the BMP recommendation did not include additional manure-hauling costs.

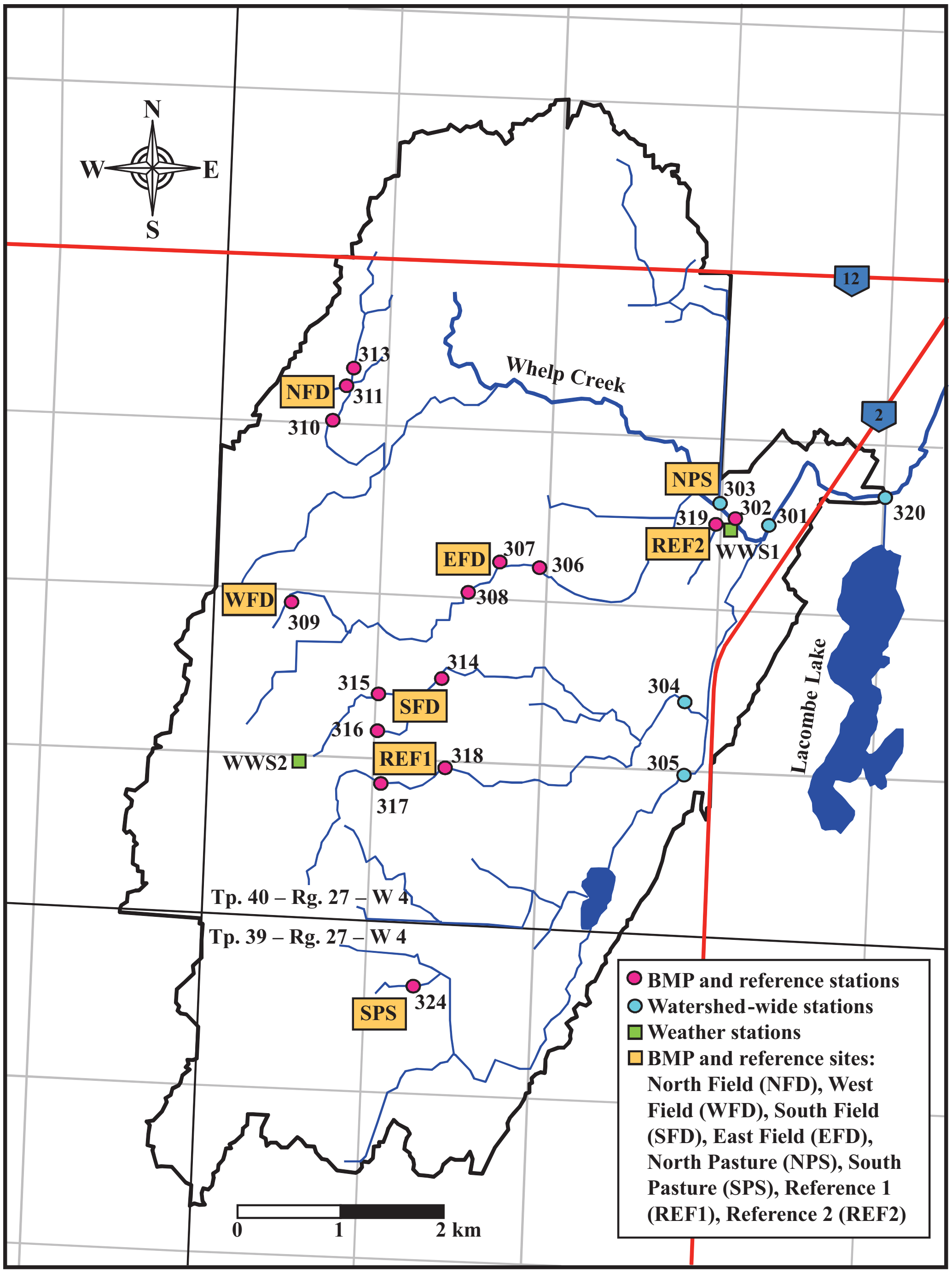


Figure 5.14. Location of the Whelp Creek Sub-watershed beneficial management practices sites and water monitoring stations.

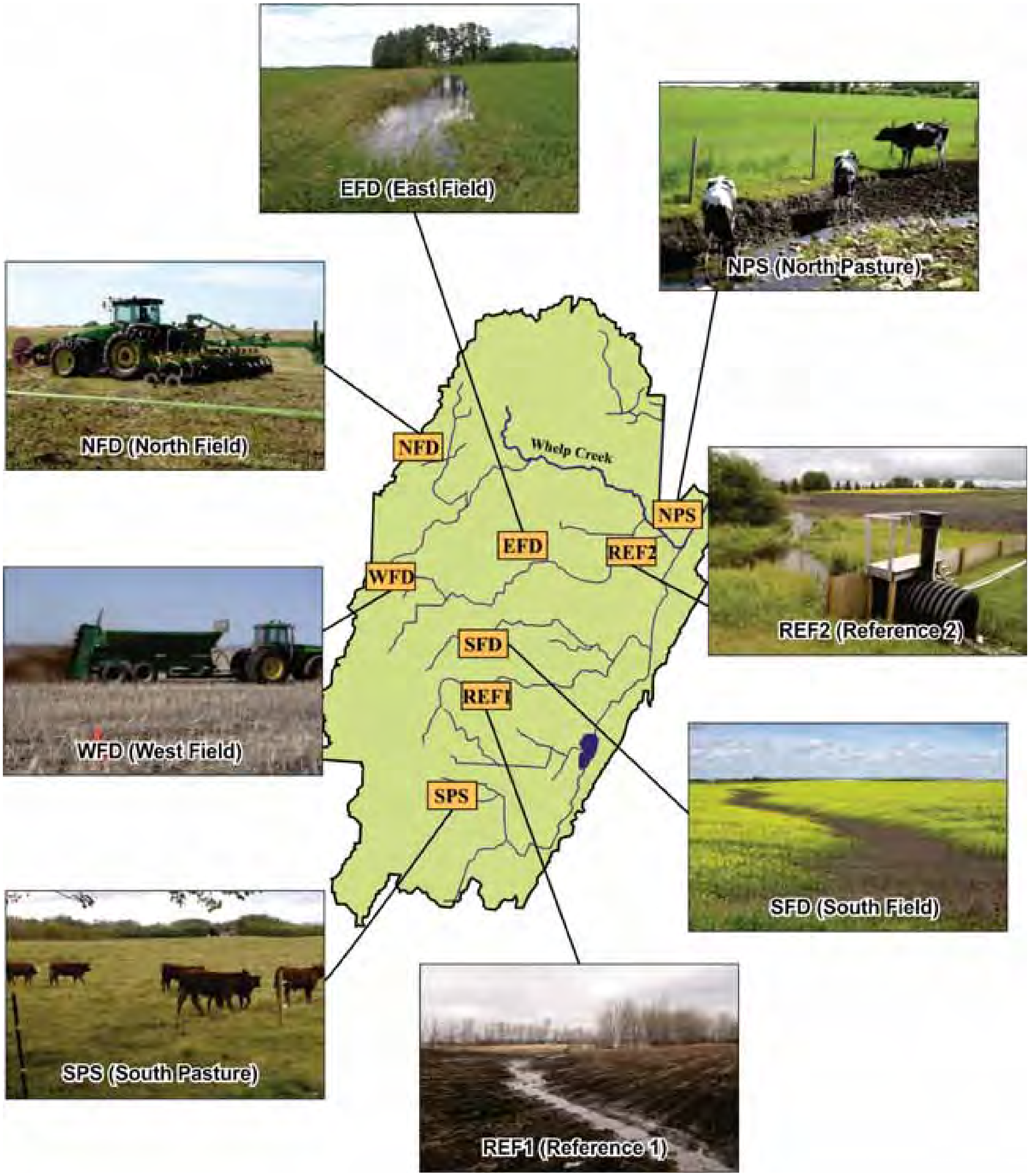


Figure 5.15. Overview of the beneficial management practices sites.

Table 5.3. A description of issues and beneficial management practices (BMPs) plans for the Whelp Creek Sub-watershed BMP sites.

Site[z]	Type[y]	Issues	BMP plan
NFD	N	• Runoff from manured fields into a tributary • Moderately elevated soil P • Surface applied liquid manure • Storage of manure next to tributary • Eroded drainage channel	• Manure application setbacks • Apply manure based on P crop removal • Change to injected manure application • Relocated manure storage • Erosion control on a drainage channel
WFD	N	• Manure applied through a shallow drainage channel within a field	• Manure application setbacks • Apply manure based on P crop removal • Change to spring manure application
EFD	N	• Manure applied through a drainage channel within a field.	• BMP plan not successfully implemented
SFD	N	• Manure applied through a drainage channel within a field	• Manure application setbacks • Apply manure based on P crop removal • Buffer zone at drainage outlet
NPS	C	• Direct access by cattle to the creek • Degraded riparian area • Over grazing	• Exclude cattle from degraded riparian area • Localized bioengineering • Increase pasture size • Pasture rest with no grazing; weed control
SPS	C	• Direct access by cattle to a drainage channel within the pasture • Over grazing	• Rotational grazing among paddocks created with new fencing and water system

[z] NFD = North Field, WFD = West Field, EFD = East Field, SFD = South Field, NPS = North Pasture, and SPS = South Pasture.

[y] C = cattle management BMPs involved infrastructure alterations, off-stream watering, windbreaks, fencing, and/or improved grazing plans; N = manure nutrient management BMPs on cropland involved nutrient management plans, application setbacks, and/or buffer zones.

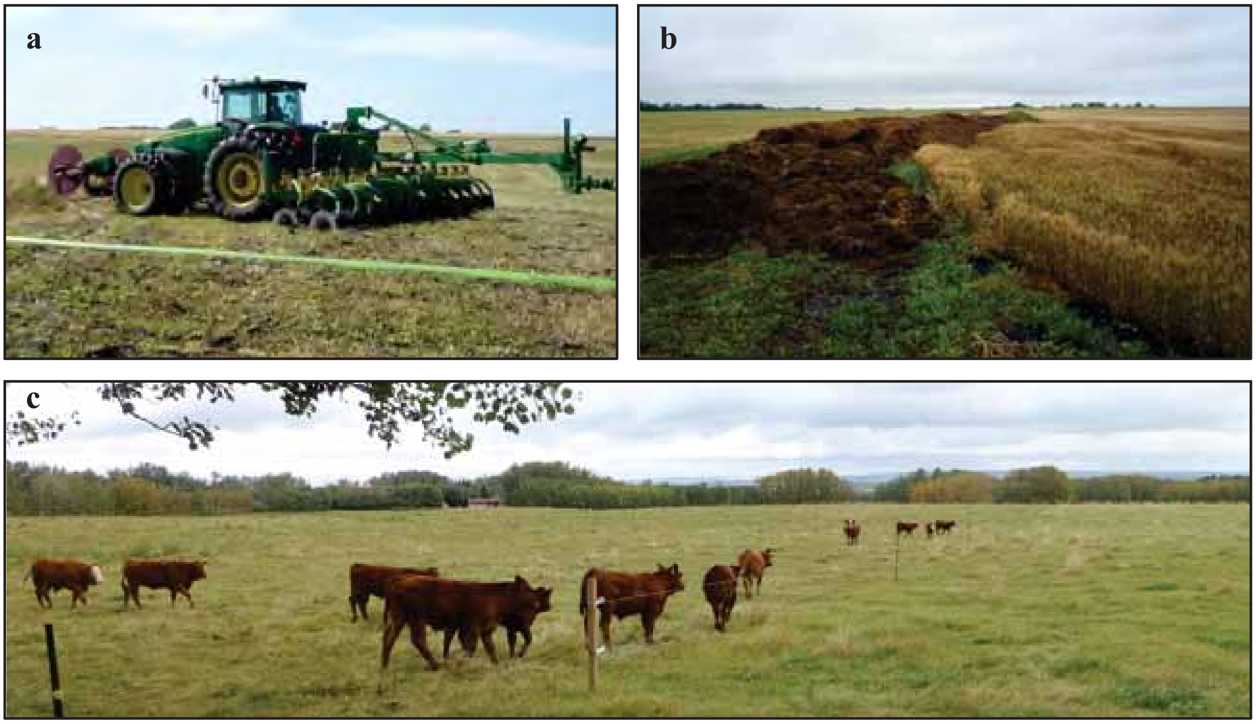


Figure 5.16. Images showing (a) dairy manure injection and (b) relocated manure storage at the North Field site, and (c) cattle grazing in one of the paddocks created using electric fence.

Table 5.4. Total cost of beneficial management practices at sites in the Whelp Creek Sub-watershed.

Site	Cost ($)	Labour (hours)
NFD	5775	16
WFD	830	17
SFD	1265	33
NPS	466	52
SPS	3340	44

6 BATTERSEA DRAIN FIELD SITE

6.1 Site Description and Management

The BDF site was located on 65 ha of land in the Battersea Drain Watershed about 30 km northeast of Lethbridge (Figure 6.1). The site was in an area of high agricultural intensity including confined feeding operations and irrigated crop production. The site was bisected by the Battersea Drain from the southwest to the northeast corners (Figure 6.2). A water supply dugout for the landowner's feedlot was in the southwest corner of the field, and a smaller dugout for the pivot irrigation system was in the northwest corner. Both dugouts were filled from a small irrigation canal at the southwest corner upstream from the BDF site.

During the study, the four-year crop rotation included barley silage, potato, corn silage, and canola. Irrigation water was applied using a low-pressure, drop-tube centre pivot irrigation system (Figure 6.3). Prior to BMP implementation in fall 2008, the field regularly received applications of beef cattle manure.

Annual average daily temperature ranged from 4.6 to 6.2 °C from 2007 to 2012, with an overall average of 5.2 °C, compared to the 30-year average of 5.7 °C. Total annual precipitation ranged from 255 to 451 mm, compared to the 30-year average of 365 mm. Precipitation at the site was similar to the Iron Springs weather station in 2009 and 2010 and about 20% more in 2011 (Figure 6.4).

The pre-BMP years (2007 and 2008) were generally warmer and drier than the post-BMP years (2009 to 2012). The average temperature was 5.7 °C for the pre-BMP years and 5.1 °C for the post-BMP years. The average annual precipitation was 332 mm for the pre-BMP years and 399 mm for the post-BMP years.

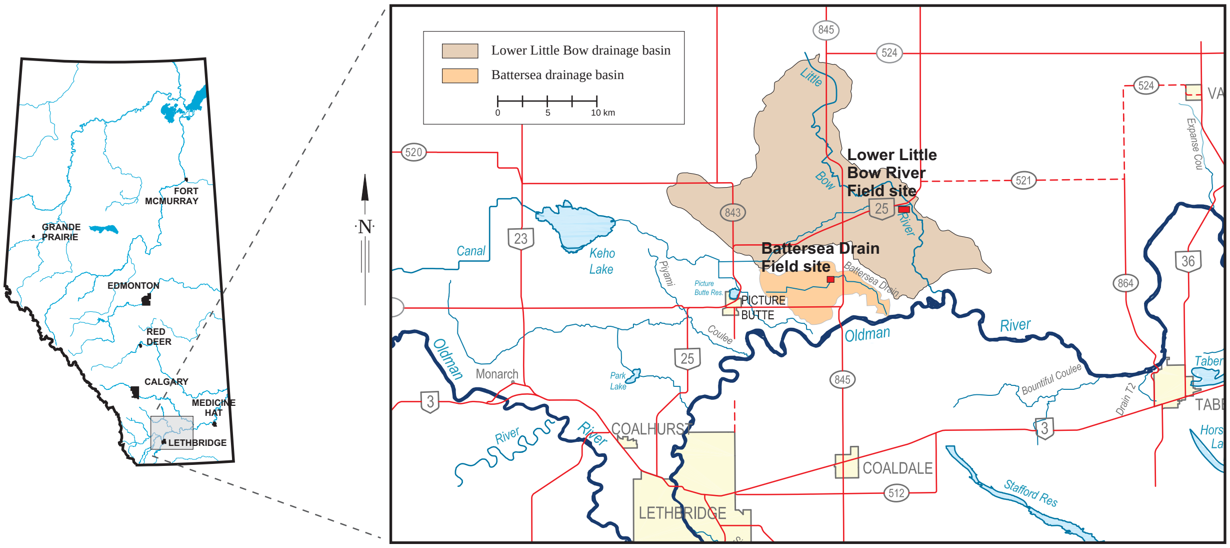


Figure 6.1. Location of Battersea Drain Field and Lower Little Bow Field sites.

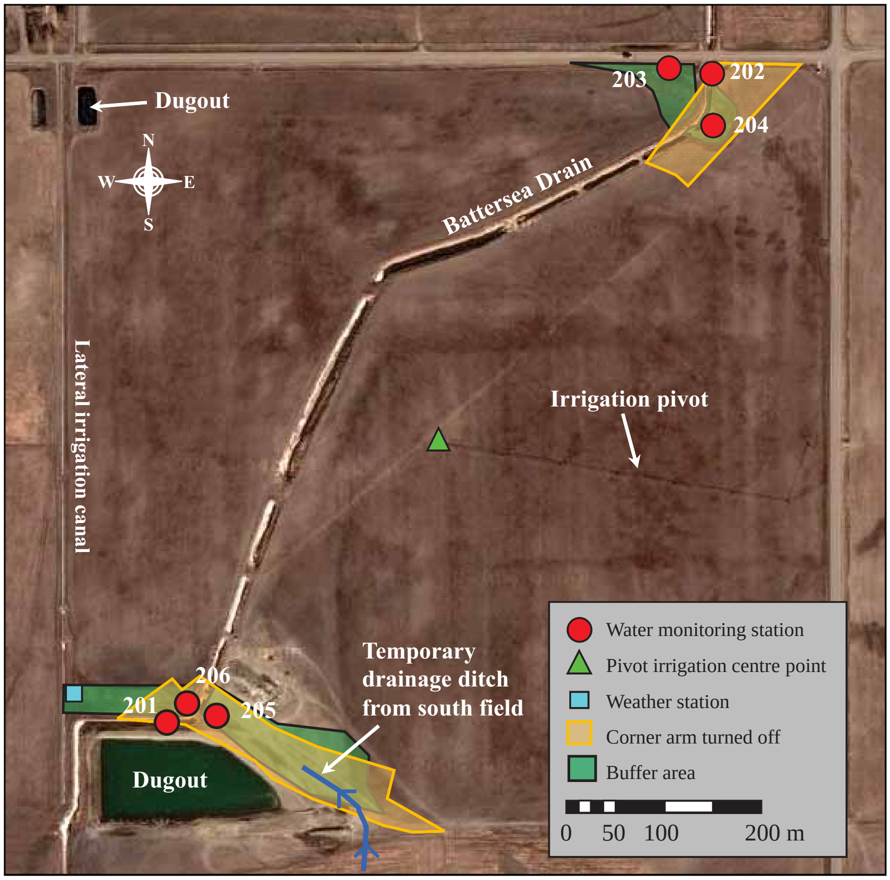


Figure 6.2. Battersea Drain Field site.

Figure 6.3. The low-pressure, drop-tube pivot irrigation system at the Battersea Drain Field site.

6.2 Soil Quality

Previous studies found high concentrations of STP at this site, with values ranging from about 323 to 738 mg kg^{-1} in the top 15 cm of soil in 2002 (Riemersma et al. 2004). During the current study, the average STP concentration in the 0- to 15-cm layer was 405 mg kg^{-1}, which is about seven times higher than the agronomic threshold of 60 mg kg^{-1}, above which crops will generally not respond to added P (Howard 2006).

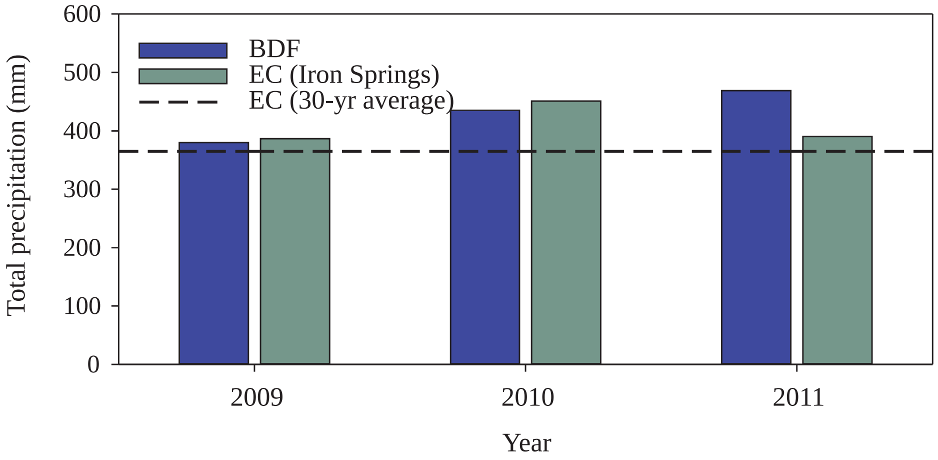


Figure 6.4. Total precipitation at the Battersea Drain Field weather station and the Environment Canada Iron Springs weather station (2009 to 2011).

Of interest was the STP concentration in the 15- to 30-cm layer, which averaged about 155 mg kg^{-1} for the same years. Soil-test P concentrations of about 33 mg kg^{-1} were found in the 30 to 60-cm layer. This suggests that P leached further into the soil profile. Olson et al. (2010a) showed that when surface soil becomes saturated with accumulated P, the risk of P leaching can increase.

Extractable NO_3-N concentration was relatively consistent throughout the 3-m soil profile, with values that ranged from 8 to 29 mg kg^{-1}. There was no obvious accumulation of NO_3-N below the root zone (>1.5 m), which suggests that nitrate was leached with irrigation water. Nitrate leaching is a concern when irrigating coarse-textured soils such as the soils at this site.

6.3 Water Flow and Quality

Annual flow of water measured in the Battersea Drain at the downstream Station 202 ranged from 4.9 million m^3 yr^{-1} in 2009 to 6.5 million m^3 yr^{-1} in 2012, with an average of about 5.7 million m^3 yr^{-1}. More than 90% of the annual flow occurred from late-April/early-May to mid-October. The initial increase in flow each spring was caused by snow and ice melting in the drain. High flow in the drain during the growing season was sustained by water released from the Picture Butte Reservoir for irrigation and field runoff.

Flow at the four edge-of-field stations ranged from 0 to 9030 m^3 yr^{-1} during six years of monitoring. Annual runoff flow through the edge-off-field stations was small compared to the flow in the Battersea Drain, representing less than 0.4% of the average annual flow. On average, 21% of the annual runoff flow was caused by snowmelt, 42% by rainfall, and 31% by irrigation.

Prior to the implementation of BMPs (2007 and 2008), the average TN and TP concentrations were higher in rainfall runoff compared to irrigation runoff at the edge-of-field; whereas, the concentration of TSS was less during rainfall (Table 6.1). The high concentration of TP in runoff, of which the majority was TDP, reflected the high STP levels in the field.

Table 6.1. Average water quality parameter concentrations at the edge-of-field during the pre-BMP (2007 to 2008) period at the Battersea Drain Field[z].

Event	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	*E. coli*	EC
		(mg L^{-1})								(mpn 100 mL^{-1})	(µS cm^{-1})
Rainfall	49	10.5	8.01	1.93	0.40	6.22	5.92	0.29	12	1666	2404
Irrigation	33	4.19	3.75	0.29	0.10	2.58	2.17	0.41	120	5236	1377
Growing season[y]	82	7.93	6.30	1.27	0.28	4.76	4.41	0.34	56	3103	1991

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, *E. coli* = *Escherichia coli*, EC = electrical conductivity.

[y] Growing season = rainfall plus irrigation events. No snowmelt runoff occurred during the pre-BMP period.

6.4 Beneficial Management Practices

The main concerns for this site were the elevated STP concentration, and the high concentrations of N, P, sediment, and bacteria in the edge-of-field runoff. The BMPs were designed to address nutrient source and transport (Table 6.2).

To reduce the source of nutrients, the BMPs that were implemented included:

- The cessation of P application including manure; and
- A nutrient management plan for N.

Irrigation management BMPs were also implemented to address the transportation of nutrients, and included:

- Modification of the pivot irrigation system; and
- Utilization of the Alberta Irrigation Management Model (AIMM), which is a decision support tool used to assist producers to effectively schedule irrigation everts (ARD 2013b).

The overall cost for the BMPs was nearly $43,600, of which 69% was needed for hauling manure a further distance for two years. The remaining costs were mainly related to a new irrigation control panel and shut-off control valves.

Table 6.2. A description of issues and beneficial management practices plans for the Battersea Drain Field.

BMP type[z]	Issues	BMP plan
N	• Very high level of soil P from manure application	• Stop manure application and nutrient management plan
S	• Field drains into an irrigation canal including irrigation generated runoff	• Pivot modification and irrigation management to control runoff from irrigation

[z] N = manure nutrient management BMPs; S = surface-water management.

7 LOWER LITTLE BOW FIELD SITE

7.1 Site Description and Management

The LLB site was an irrigated field located northeast of Lethbridge, Alberta (Figure 6.1). The site included two adjacent 65-ha fields (Figure 7.1). During the study, the site was used for annual crop production. However, forages were grown there in the past. The site was in the Lethbridge Northern Irrigation District and was irrigated with two low-pressure, drop-tube centre pivot irrigation systems.

Beef cattle manure from the producer's nearby feedlot had been applied regularly to the site (Figure 7.2), which resulted in high soil P concentrations.

The site had a single main drainage channel, which flowed towards the northeast corner of the site (Figure 7.1). From there it flowed into a culvert under the road and then into a 1.5-km long coulee, which discharged into the Lower Little Bow River. The drainage channel had been mechanically altered in the past.

The pre-BMP years (2007 and 2008) were generally warmer and drier than the post-BMP years (2009 to 2011). The average temperature was 5.7 °C for the pre-BMP years and 4.8 °C for the post-BMP years. The average annual precipitation was 332 mm for the pre-BMP years and 409 mm for the post-BMP years. Annual total precipitation at the LLB weather station was similar to the Environment Canada (EC) Iron Springs station (Figure 7.3).

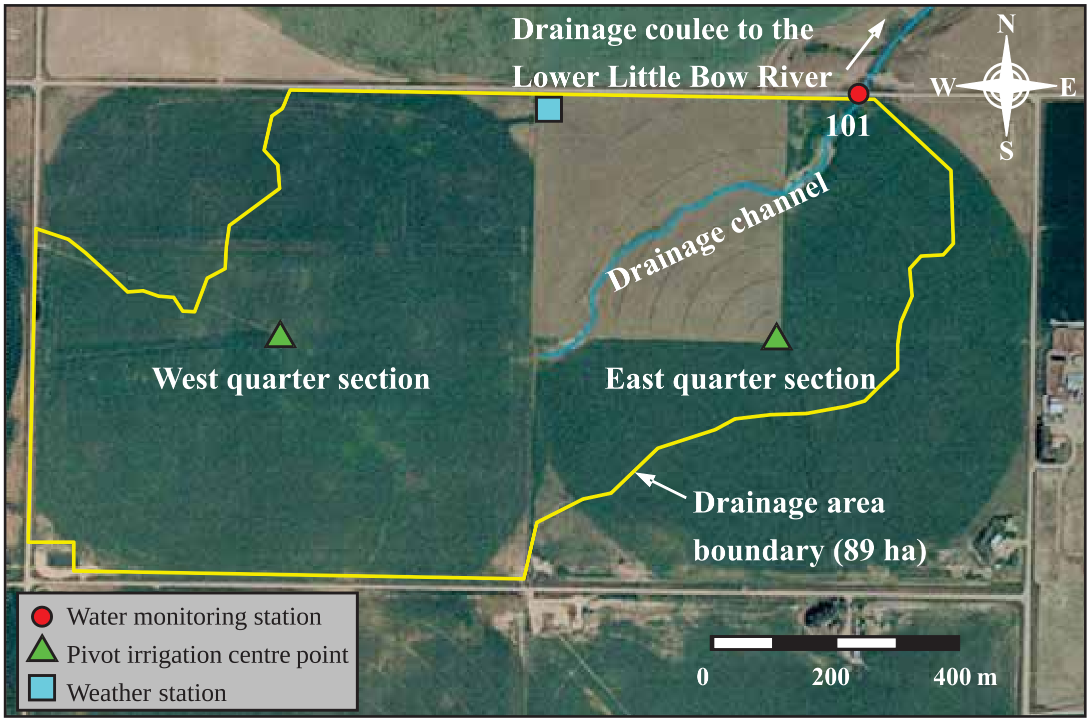


Figure 7.1. Lower Little Bow Field site showing drainage area and channel.

7.2 Soil Quality

The LLB site was previously used in the Alberta Soil Phosphorus Limits Project to monitor water and soil phosphorus from 2002 to 2005 (Little et al. 2006). Little et al. (2006) reported the annual mean STP ranged from 236 to 269 mg kg^{-1}, which is slightly less than was found during the current BMP Project (Figure 7.4). The five-year average for STP at this site was 280 mg kg^{-1}, which was about five times the agronomic threshold of 60 mg kg^{-1} (Howard 2006). The elevated STP and the high concentrations of nutrients in the runoff were the main concerns with this site.

Figure 7.2. Spreading beef manure.

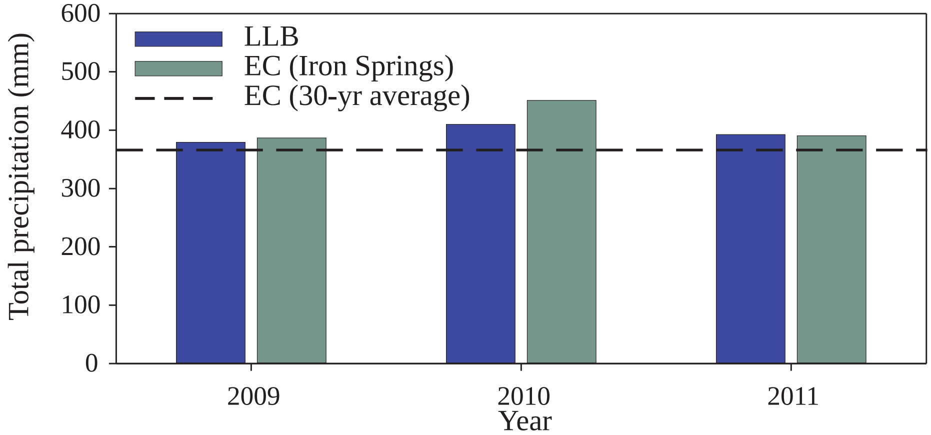


Figure 7.3. Total precipitation at the Lower Little Bow Field weather station and Environment Canada Iron Springs weather station (2009 to 2011).

7.3 Water Flow and Quality

The annual runoff flow in the pre-BMP years (2003 to 2008), including results from the P Limits Project (Little et al. 2006), were quite variable (Table 7.1). Most runoff flow was generated during the growing season by rainfall and/or irrigation.

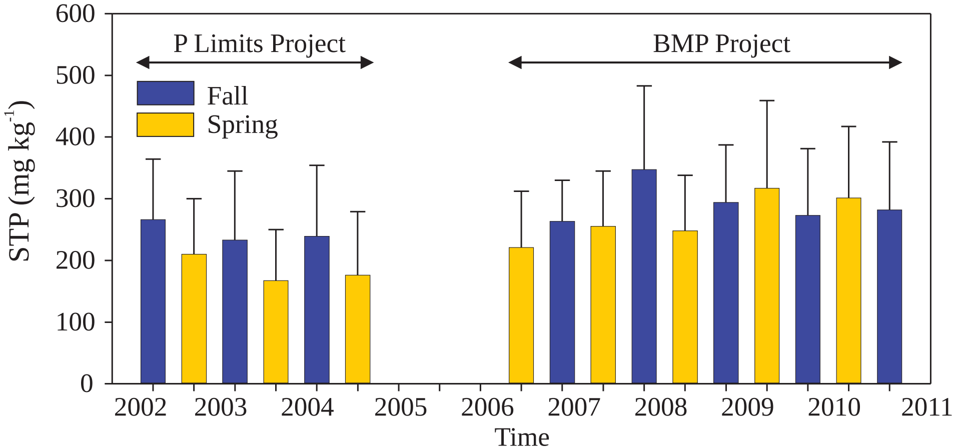


Figure 7.4. Comparison of fall soil-test phosphorus (STP) concentrations (0 to 15 cm) at the Lower Little Bow Field for (a) the Alberta Soil Phosphorus Limits Project and (b) the current BMP Project. T-bars are standard deviations.

The concentration for most water quality parameters was higher in rainfall runoff compared to irrigation runoff, except for PP, TSS, and *E. coli* (Table 7.2). Overall, the majority of the TN was in the form of ON and most of the TP was in TDP form.

7.4 Beneficial Management Practices

Beneficial management practices were developed for this site to address the source and transport of nutrients. The BMPs implemented to address nutrient source included (Table 7.3):

- The cessation of manure application to address soil P concentration; and
- The use of a nutrient management plan for soil N.

The BMPs implemented to address nutrient transport included:

- Modification of the pivot irrigation system to limit water application in the drainage channel (Figure 7.5);

Table 7.1. Runoff flow measured at the Lower Little Bow Field (2003 to 2008).

Year[z]	Flow (m^3 yr^{-1})	Percent from snowmelt	Percent from rainfall	Percent from irrigation
2003	2,968	38	5	57
2004	801	32	0	68
2005	11,238	0	92	8
2007	1,082	na[y]	na[x]	100
2008	11,637	0	40	60

[z] 2003 to 2005 data from Little et al. (2006); 2007 to 2008 data from the current study. No data collected in 2006.

[y] Not available: Two minor events occurred in mid and late February, but flows were not recorded.

[x] Not available: Small amounts of runoff occurred from rainfall on April 19 and May 4, but flows were not recorded.

Table 7.2. Average water quality parameter concentrations during the pre-BMP (2007 to 2008) period at the Lower Little Bow Field.[z]

Event	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	*E. coli*	EC
		------------------------------- (mg L^{-1}) ---------------------------								(mpn 100 mL^{-1})	(µS cm^{-1})
Rainfall	15	14.1	6.81	6.33	0.60	3.81	3.63	0.18	38	1231	4139
Irrigation	12	5.94	5.03	0.57	0.17	2.67	2.38	0.28	43	4491	2953
Growing season[y]	27	10.5	6.02	3.77	0.41	3.30	3.07	0.22	40	2680	3612

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, *E. coli* = *Escherichia coli*, EC = electrical conductivity.

[y] Growing season = rainfall plus irrigation events. No snowmelt runoff occurred during the pre-BMP period.

- Utilization of the Alberta Irrigation Management Model (AIMM), to schedule irrigation events (ARD 2013b); and
- Establishment of grass cover in the drainage channel (Figure 7.5).

Soil and runoff water quality were monitored for two years (2007 and 2008) prior to the implementation of the BMPs.

The BMPs were implemented in fall 2008 and spring 2009, and monitoring continued until 2011.

The overall cost for the BMPs was nearly $76,700, of which 78% was needed for hauling manure a further distance for two years. The remaining costs were mainly related to a new irrigation control panel and shut-off control valves.

Table 7.3. A description of issues and beneficial management practices plans for the Lower Little Bow Field.

BMP type[z]	Issues	BMP plan
N	• Very high level of soil P from manure application	• Stop manure application and nutrient management plan
S	• Field drains into a coulee channel including irrigation generated runoff	• Pivot modification and irrigation management to control runoff from irrigation • grass cover in drainage channel

[z] N = manure nutrient management BMPs; S = surface-water management.

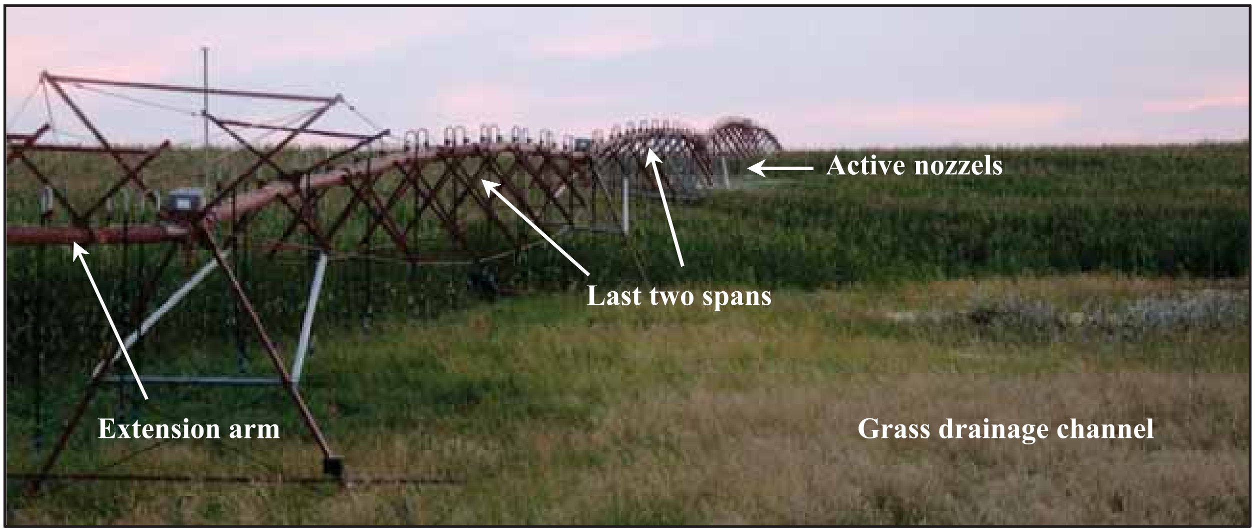


Figure 7.5. Pivot irrigation system at the Lower Little Bow site. The last two spans and extension arm nozzles were turned off when the pivot was in the drainage channel.

8 FIELD STUDY RESULTS

8.1 Introduction

The purpose of this section is to provide an overall synthesis of findings from the watershed field study component of the BMP Project and situate the findings within a provincial context.

8.2 Project Watershed Comparisons

The IFC and WHC watersheds were relatively small, ephemeral streams that were dominated by agricultural land use (Figures 4.1 and 5.1). The BDF and LLB sites were irrigated and in an intensive livestock feeding area (Figure 6.1). Both field sites had a history of extensive beef manure application.

The IFC Watershed, and BDF and LLB sites were located in the Grassland Natural Region of southern Alberta, while the WHC Sub-watershed was located in the Parkland Natural Region of central Alberta.

Indianfarm Creek generally began flowing in February and Whelp Creek and the Battersea Drain generally began flowing in March (Figure 8.1). The average daily flow in all three streams was typically less than 1 $m^3 s^{-1}$. Indianfarm Creek tended to flow about two months longer and had higher daily flows than WHC, and hence, IFC tended to generate more flow than WHC. The flow in IFC was primarily driven by rainfall in the spring while almost half of the runoff in WHC was derived from snowmelt (Table 8.1).

While there were some similarities between the study watersheds, there were also differences (Table 8.1). The differences were inherent in the landscape, hydrology, and farming practises. The IFC Watershed was the largest of the project watersheds at about twice and three times the size of the Battersea and WHC watersheds, respectively. The watersheds were located in two natural regions (Table 8.1), which were reflected by the differences in the average annual precipitation.

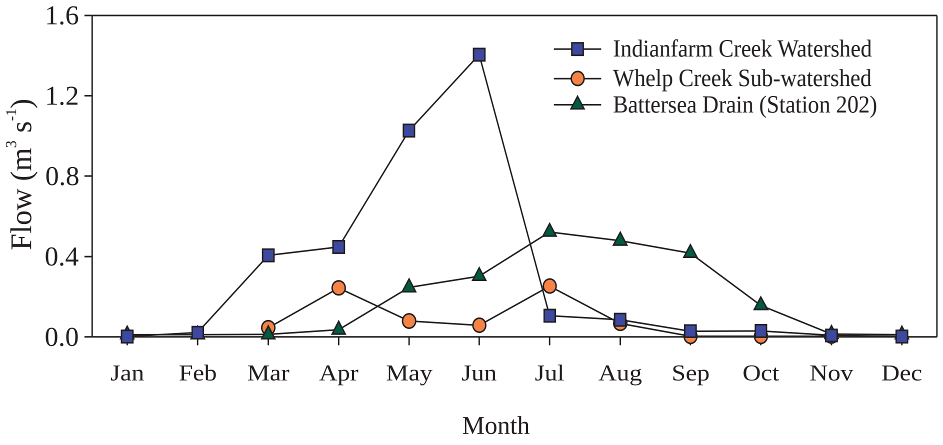


Figure 8.1. Annual average hydrographs for the outlets of Indianfarm Creek Watershed and Whelp Creek Sub-watershed and Battersea Drain.

Table 8.1. Characteristics of the Nutrient Beneficial Management Practices Evaluation Project watersheds and field sites.

Characteristics	Indianfarm Creek Watershed	Whelp Creek Sub-watershed	Battersea Watershed	Irrigated fields (BDF, LLB)[z]
Watershed size (ha)	14,145	5056	7800	-
Watershed type	Natural	Natural	Irrigation	Irrigation
Natural region	Grassland	Parkland	Grassland	-
Average annual precipitation (mm)	515	446	365	-
Gradient (m)	500	90	94	11, 18
Stream channel	incised	shallow	irrigation drain	field channel
Stream velocity	flashy events	slow moving	steady	-
Average annual volume (dam^3)	9783	1722	5770	2, 16
Average daily flow ($m^3\ s^{-1}$)[y]	0.64	0.23	0.45[x,w]	0.001; 0.005
Average number days flow at outlet	176	87	183[w]	-
Average number days of runoff per year	-	-	-	22, 36
Portion of runoff as snowmelt (%)	25	45	-	20, 22
Portion of runoff as rainfall (%)	75	55	-	49, 43
Portion of runoff as irrigation (%)	0	0	-	31, 35
Annual:perennial crop-cover ratio	40:60	70:30	68:32[x]	-
Total cattle and calves	34,500	2640	427,602[v]	-
Soil zone	Black	Black	Dark Brown	-
Surface-soil texture	fine	medium	coarse-medium	-

[z] LLB based on 2003 to 2005 (Little et al. 2006) and 2008 to 2011 (current study) flow data.

[y] Average based only on days when there was flow.

[x] Lorenz et al. (2008).

[w] Average flow value based on late April to late October flows from 1995 to 2006.

[v] Data source is Statistics Canada, 2011 Census of Agriculture and are for Lethbridge County. While the Battersea Watershed occupies a relatively small land base in the county, the majority of county's confined feeding operations are located within the Battersea Drain area.

Topographic relief was greater in IFC than WHC and subsequently flow in IFC was flashy; whereas, flow in WHC was generally shallow and slow moving. The Battersea Drain forms part of the return flow from the Lethbridge Northern Irrigation District, and flow tended to be steady during the growing season. Runoff from irrigated fields was small as the large majority of irrigation is by pivot sprinkler systems.

While mixed farming occurred within all of the watersheds, the farm practises varied. Within IFC Watershed, cow-calf livestock management predominated and much of the crop cover was in perennial forage (Table 8.1). In contrast, farming in WHC and the Battersea areas tended to include more intensive livestock practises, resulting in significant manure management challenges.

8.3 Water Quality

- Water quality in the watersheds mirrored the differences between the study watersheds.
- Whelp Creek typically had higher nutrient concentrations than IFC (Figure 8.2).
- Total suspended solids concentrations in IFC were about 3 to 10 times higher than BDF and WHC.
- The proportion of PP in IFC tended to be higher than BDF and WHC.
- Whelp Creek tended to have a higher proportion of ON than IFC and BDF, and this may be related to the higher proportion of runoff that occurred as snowmelt (Casson et al. 2008).
    - ➢ The higher nutrient concentrations in WHC were likely related to its higher agriculture intensity than IFC.
    - ➢ While nutrient concentrations in WHC were higher, the load and export coefficient of nutrients from WHC were lower than the other study watersheds (Figure 8.2).
    - ➢ Differences in export coefficients have previously been observed in many of Alberta's agricultural watersheds (Lorenz et al. 2008).
    - ➢ Flow was the primary driver for the observed load and export differences at the BMP Project watershed outlets.

Average *E. coli* concentrations appeared higher in the mainstem than at the tributary and edge-of-field sites in WHC; whereas, bacteria concentrations were not related to scale in IFC (Figure 8.3).

8.4 Soil Nutrients

Agronomic soil samples were collected at many of the BMP Project sites to assess the nutrient status of surface soil. The results provide an opportunity to compare the status of extractable N and P in soil from several different fields and to determine the relationships with the loss of N and P in edge-of-field runoff water. For comparison purposes, the cultivated field sites from all watersheds were classified as no manure, manured, or heavily manured. Pasture sites were placed in a fourth category.

8.4.1 Nutrient Concentration

As manure intensity increased, the average concentration of soil NO_3-N increased. The average concentration of NO_3-N was 14 mg kg^{-1} for no manure sites, 24 mg kg^{-1} for manured sites, and 36 mg kg^{-1} for heavily manured sites (Figure 8.4a). These findings are similar to those found in Casson et al. (2008), where the average 0- to 15-cm soil NO_3-N concentration was 22 mg kg^{-1} for no manure sites, 73 mg kg^{-1} for manured sites, and 3 mg kg^{-1} for an un-grazed grassland site. Unlike NO_3-N, the average concentration of NH_4-N was relatively consistent, ranging from 6 to 9 mg kg^{-1} among the four manure rate categories (Figure 8.4b). This was not surprising as NH_4 tends not to accumulate in soil, and is converted to NO_3 through nitrification.

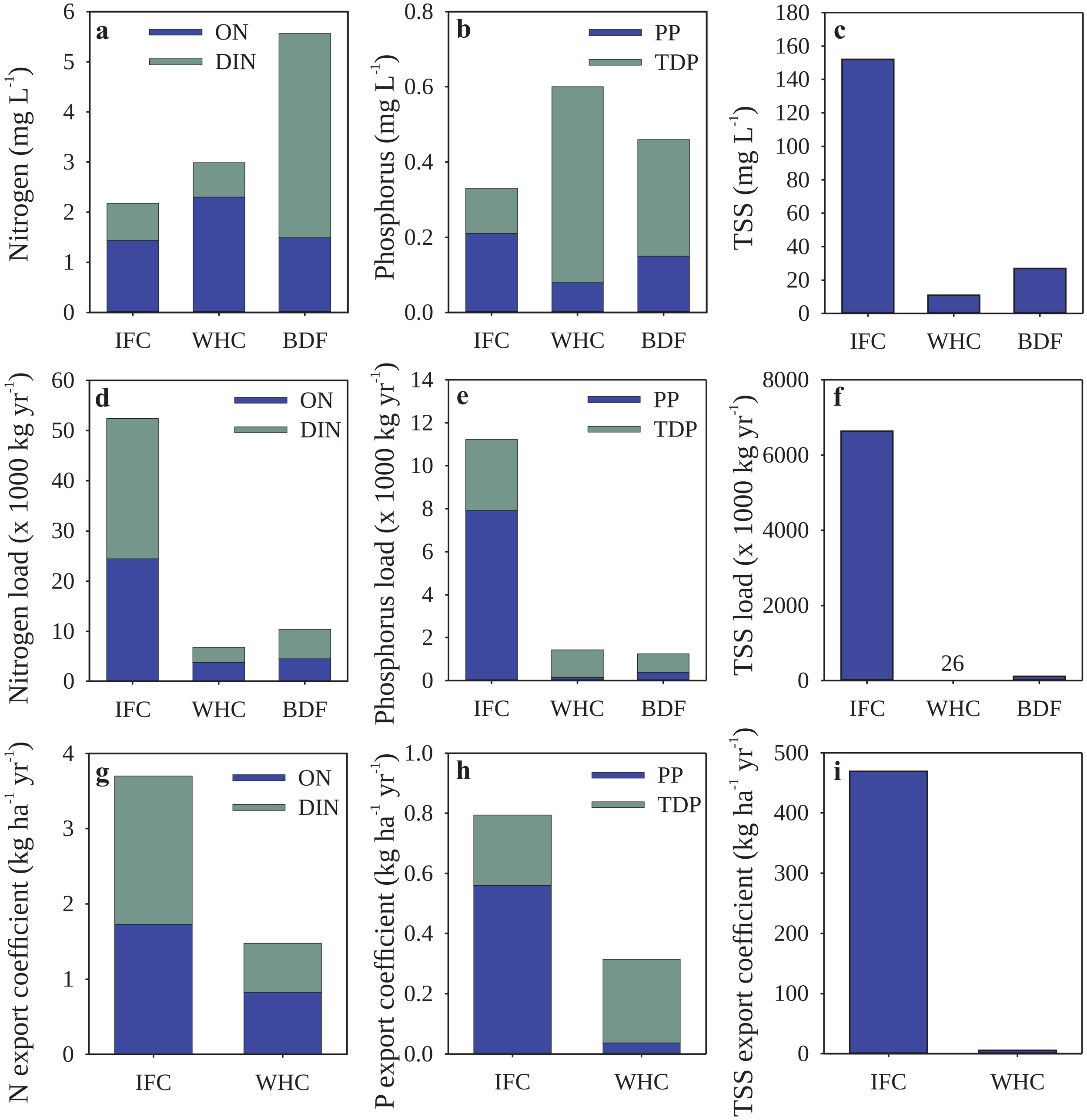


Figure 8.2. Average (a, b, c) concentrations and (d, e, f) loads at the outlets of the Indianfarm Creek and Whelp Creek watersheds and in the Battersea Drain. Average (g, h, i) export coefficients at the outlets of the Indianfarm Creek and Whelp Creek watersheds for organic nitrogen (ON), dissolved inorganic nitrogen (DIN), particulate phosphorus (PP), and total dissolved phosphorus (TDP).

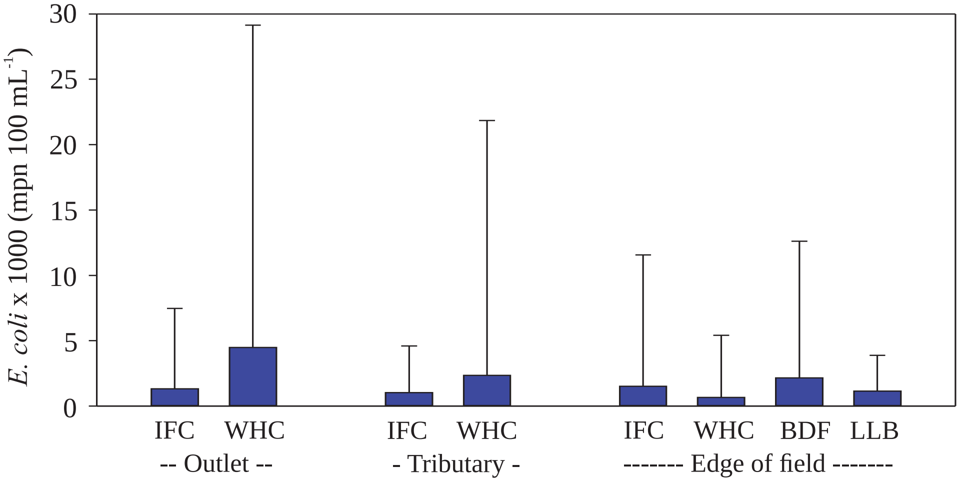


Figure 8.3. Average *Escherichia coli* (*E. coli*) in Indianfarm Creek Watershed, Whelp Creek Sub-watershed, and Battersea Drain Field and Lower Little Bow Field sites. T-bars are standard deviation.

8.4.2 Soil-test Phosphorus

The concentrations of STP were clearly different among the manure categories, and this is similar to findings from Little et al. (2007). The average concentration of STP was 33 mg kg^{-1} for the no-manure sites (Figure 8.4c), and more than 70 mg kg^{-1} for manured sites. For the two heavily manured sites, the average STP concentration was nearly five-fold greater than manured soils. All of the no-manure sites had STP values below the agronomic threshold of 60 mg kg^{-1} (Howard 2006). The average concentration for the pasture sites was intermediate between the no-manure and manured sites.

8.5 Link between Soil Nutrients and Runoff Water Quality

8.5.1 Soil Phosphorus

Several studies have shown relationships between nutrients in soil and nutrient loss in runoff water, particularly for P, including work in Alberta by Little et al. (2007). In the current study, 13 of the 20 sites shown in Figure 8.4 were for edge-of-field runoff water quality monitoring. The results from these 13 sites showed that the concentration of TP in runoff water increased as the concentration of STP increased (Figure 8.5b,c). A similar relationship was also observed for TDP in runoff. The curve-linear relationship reported is in contrast to the linear relationship reported by Little et al. (2007).

8.5.2 Soil Nitrogen

There was no relationship between soil extractable NO_3-N, and TN in runoff water (Figure 8.5a). This was also true for NO_3-N concentration in the soil compared to NO_3-N in runoff water soil. These results support other work in Alberta by Casson et al. (2008).

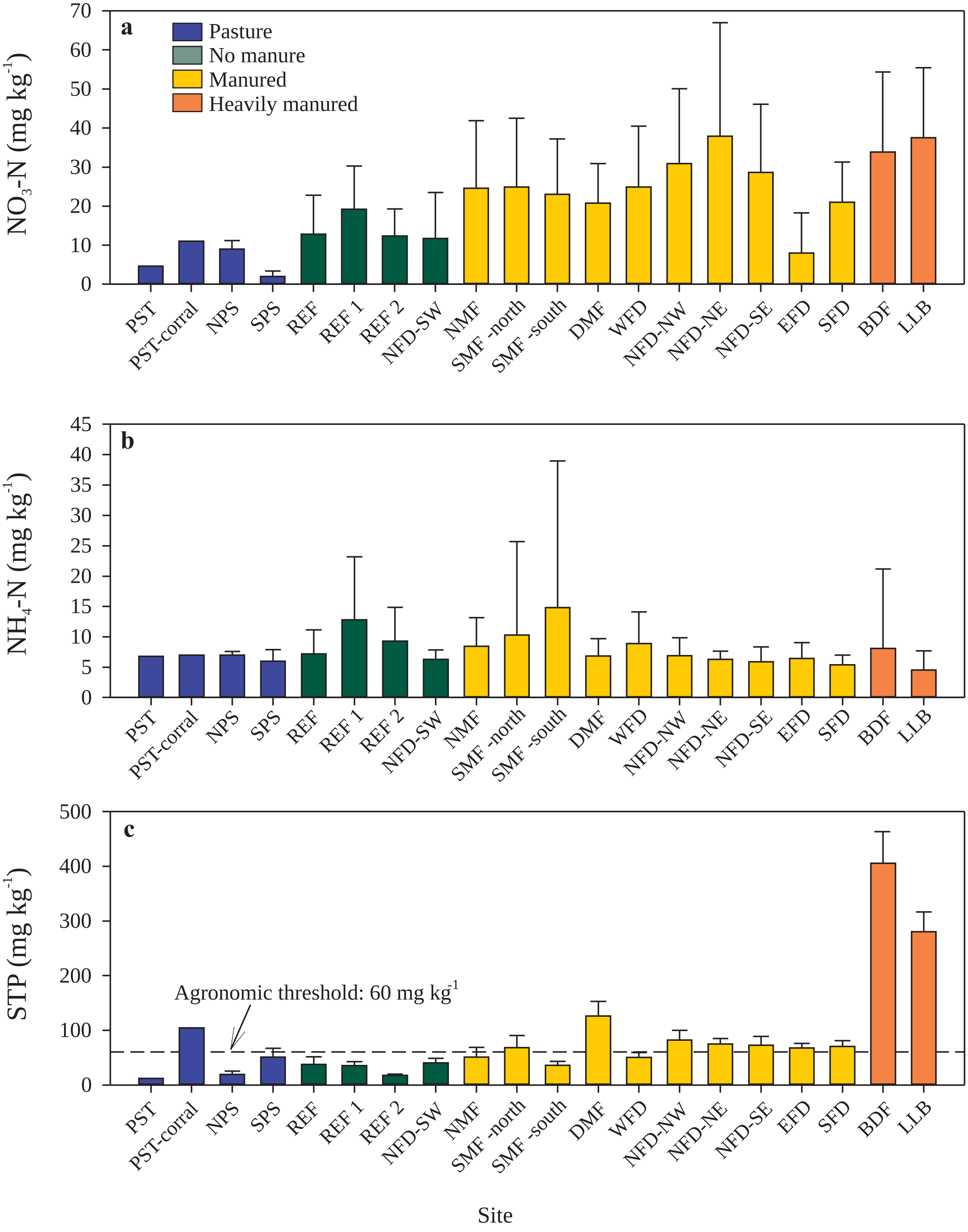


Figure 8.4. Average concentration of (a) nitrate-nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and (c) soil-test phosphorus (STP) in the surface soil (0 to 15 cm) at the Nutrient Beneficial Management Practices Evaluations Project sites. T-bars are standard deviations.

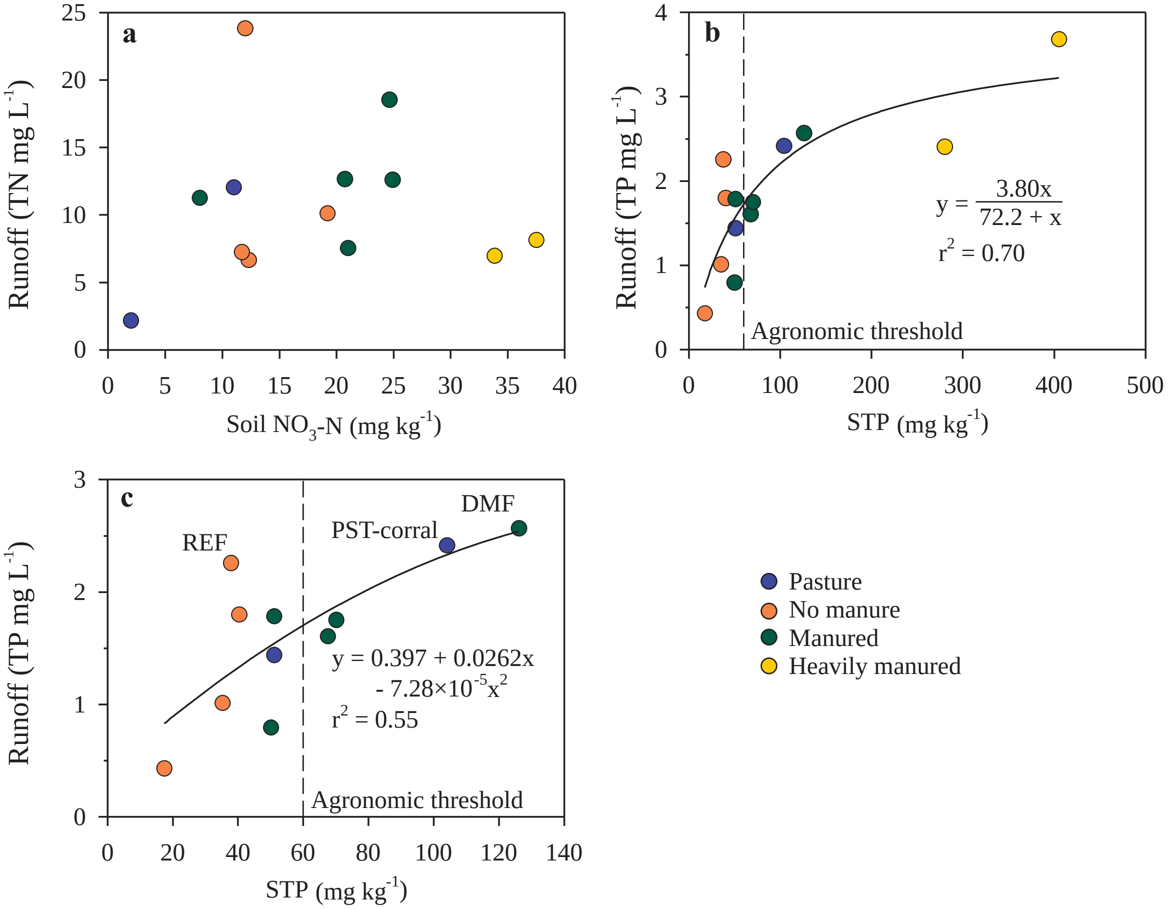


Figure 8.5. The relationships between (a) soil extractable nitrate-nitrogen (NO_3-N) and total nitrogen (TN) in edge-of-field runoff water, and (b, c) between soil-test phosphorus (STP) and total phosphorus (TP) in edge-of-field runoff water.

8.6 Assessment of Beneficial Management Practices

A total of 22 sites were established in the IFC Watershed, WHC Sub-watershed, and LLB and BDF field sites as part of the BMP Project.

The BMPs for each of the sites were classified based on water quality concerns related to livestock, crop nutrients, and/or surface-water management. In the original project design, there were plans to implement BMPs at 20 of the sites. Table 8.2 provides an overview of the key features related to BMP implementation and assessment at each of the project sites.

- Successful BMP implementation occurred at 16 of the project sites.
- BMP impact on water quality was assessed at 11 sites.
- The effectiveness of BMPs was assessed at three additional sites using riparian and rangeland assessments.
- It was recognized from the beginning that multiple BMPs needed to be designed and implemented at each study site to address the effects of on-farm management on water quality.

Table 8.2. Summary of the Nutrient Beneficial Management Practices Evaluation Project sites.

Location	Site[z]	Type[y]	BMP plan developed	BMP plan successfully implemented	BMP evaluation carried out				
					Water quality	Water quantity	Soil quality	Riparian	Rangeland
Indianfarm Creek Watershed	IMP	C	✓	✓	✓			✓	
	NMF	C	✓	✓	✓				
	PST	C	✓	✓	✓			✓	✓[x]
	WIN	C	✓	✓	✓			✓	
	SMF[w]	C	✓						
	DMF[v]	N	✓						
	REF[u]	C	✓						
	FLT[t]	C,S	✓	✓					✓[s]
	DUG	C	✓	✓				✓	
	OSW	C	✓	✓				✓	
	FEN[r]	C	✓	✓					
	CAT	S	✓	✓					
Whelp Creek Sub-watershed	WFD	N	✓	✓	✓				
	NFD	N	✓	✓	✓				
	EFD[q]	N	✓						
	SFD	N	✓	✓	✓				
	NPS	C	✓	✓	✓				✓[p]
	SPS	C	✓	✓	✓				✓[p]
	REF1[o]								
	REF2[o]								
Irrigated field sites	BDF	N,S	✓	✓	✓	✓	✓		
	LLB	N,S	✓	✓	✓	✓	✓		
Number of sites	22		20	16	11	2	2	5	4

[z] IMP = Impoundment, NMF = North Manure Field, PST = Pasture, WIN = Wintering, SMF = South Manure Field, DMF = Dairy Manure Field, REF = Reference, FLT = Feedlot, DUG = Dugout, OSW = Off-stream Watering, FEN = Fencing, CAT = Catch Basin, WFD = West Field, NFD = North Field, EFD = East Field, SFD = South Field, NPS = North Pasture, SPS = South Pasture, REF1 = Reference 1, REF2 = Reference 2, BDF = Battersea Drain Field, and LLB = Lower Little Bow Field.

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

[x] Rangeland survey and rangeland production.

[w] The BMP plan was not implemented due to the lack of a custom manure applicator and a late season.

[v] The BMP plan was only implemented for one year due to wet weather and field access issues.

[u] The REF site was not supposed to require a BMP. However, cattle were introduced for fall grazing and a BMP plan was developed. The plan was only implemented one year and then the BMP could not be maintained because of a crop failure, a change in crop management, and flooding of the drainage channel.

[t] Because of dry weather, an adequate number of post-BMP water samples were not obtained in order to evaluate based on water quality.

[s] Rangeland survey.

[r] As the BMP was implemented late in the project, no plan was developed to analyze water quality.

[q] The BMP plan was not implemented as the crop was switched from annual cereal to perennial forage after the planning phase. However, this site was used to assess the risk of liquid manure application on a forage crop to runoff water quality.

[p] Rangeland production.

[o] The REF1 and REF2 sites did not require BMPs.

8.6.1 Water Quality at BMP Sites

The results showed that eight of the 11 BMP sites had an improvement in water quality (Table 8.3). The BMPs were considered effective if the majority of the main parameters (TN, TP, TSS, and *E. coli*) improved (i.e., reduced concentration).

- Edge-of-field and in-stream monitoring locations showed water quality improvement. However, BMPs were most effective at improving water quality at the edge-of-field.
- Of the six BMP sites that involved cattle management, four were effective at improving water quality and one trended towards improvement. Three of the four effective BMP sites were in the IFC Watershed while one site was in the WHC Sub-watershed. Each of the effective BMPs significantly reduced one to three of the main water quality parameters (TN, TP, TSS, and *E. coli*).
- Of the six field nutrient management BMP sites, four effectively improved water quality (Table 8.3). This occurred in the WHC Sub-watershed, and BDF and LLB sites. One to all four of the main water quality parameters (TN, TP, TSS, and *E. coli*) were significantly improved.
- For the effective BMPs, concentration reductions of TN, TP, TSS, or *E. coli* ranged from 2 to 85% (Table 8.4) during runoff events.
- However, even with significant improvement, post-BMP concentrations remained relatively high. For instance, the TN reduction at the LLB site was 42% and yet, the post-BMP concentration of TN was 6.01 mg L^{-1}. This suggests that further work or additional time may be required to reduce concentrations to a more acceptable level.

8.6.2 Cumulative Effect of BMPs on Water Quality

As expected, the relatively few BMPs implemented within each watershed did not improve water quality at the outlet of the watersheds. In fact, water quality at the outlets during snowmelt and rainfall runoff tended to significantly deteriorate from the pre-BMP period to the post-BMP period, primarily due to wetter years in the post-BMP period (Table 8.5). Water quality improvement at the outlet of a watershed would require implementation of a greater number of BMPs within the critical source areas of the watershed.

8.6.3 BMP Improvement on Riparian and Rangeland Quality

Water quality was the main environmental indicator to assess the effectiveness of BMPs. However, BMP effects on riparian and rangeland quality were also assessed at some of the sites.

- The BMPs had a positive effect on riparian and rangeland quality when cattle were completely excluded or access was limited through rotational grazing (Table 8.6).
- Rangeland production was only increased if the BMP was designed to address high stocking densities.

Table 8.3. Summary of water quality changes from the pre-BMP period to the post-BMP period during active runoff events (snowmelt, rainfall, and irrigation) during the six-year study.[z]

BMP site	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	*E. coli*	Effective
Cattle management BMPs										
NMF	🟪 *	🟨 *	🟪 *	🟪 *	🟪 *	🟪 *	⬜	🟨	🟪	Yes
WIN - us/ds[y]	🟪 *	🟪 *	⬜	⬜	🟪	⬜	🟪	🟪	🟪 *	Yes
NPS - us/ds[x]	🟪	🟪 *	🟨 *	🟪 *	🟪	⬜	🟪 *	🟪 *	🟪 *	Yes
PST - corral[w]	🟪 *	🟪 *	🟪 *	🟪 *	🟪 *	🟪 *	🟪	🟪	🟪 *	Yes
PST - us/ds[v]	🟪	⬜	🟪	⬜	⬜	⬜	⬜	🟪	🟪	No
SPS	🟪	🟪	🟨	🟪 *	🟪	🟪	🟪	🟪	🟪	No
IMP	🟨	🟨 *	🟨 *	🟨 *	🟨 *	🟨 *	⬜	🟪 *	🟨	No
Field nutrient management BMPs										
NFD - 310[u]	🟪 *	🟪 *	🟪	🟪 *	🟪 *	🟪 *	🟪 *	🟪 *	🟪 *	Yes
NFD - 311[u]	🟨 *	🟨	🟨 *	🟪	⬜	🟨	🟪	🟪 *	🟪 *	Yes[t]
LLB[s]	🟪 *	🟪 *	🟪 *	⬜	🟪 *	🟪 *	🟪 *	🟪 *	🟪 *	Yes
WFD	⬜	🟨	🟪	🟨 *	🟪 *	🟪 *	⬜	🟨 *	🟨	Yes[r]
BDF - 203[q]	🟪	🟪 *	🟨 *	⬜	🟪 *	🟪	🟪	🟨	🟪 *	Yes
BDF - 204[q]	🟨 *	🟪	🟨 *	🟨	🟪	🟪	🟪	🟪 *	🟪 *	Yes
BDF - 205[q]	🟪	🟪 *	🟨	🟪	🟪	🟪	🟪 *	🟨 *	🟪 *	Yes
BDF - 206[q]	🟪 *	🟪 *	🟨	🟪 *	🟪 *	🟪 *	🟪 *	🟨	🟪 *	Yes
BDF - us/ds(High)[p,o]	🟨 *	🟨	🟨 *	🟨	🟨	⬜	🟨	🟨	🟪	No
BDF - us/ds(Low)[o,n]	🟪	🟪 *	🟪	🟪	🟨	🟨	⬜	🟪	🟪	No
SFD - 314	🟨 *	🟨 *	🟨 *	🟪 *	🟨	🟨	🟨	🟨	🟪 *	No

[z] The BMPs were considered effective if the majority of the main parameters (TN, TP, TSS, and *E. coli*) significantly improved. Most water quality changes were monitored at the edge-of-field. Four BMP sites were also monitored in-stream (upstream and downstream of the BMP) as noted by the 'us/ds' in the BMP site name.
Change in the post-BMP period compared to the pre-BMP period:

🟪 *	Significant (P <0.1) improvement
🟪	Non-significant improvement
🟨 *	Significant (P <0.1) degradation
🟨	Non-significant degradation
⬜	Little or no change

[y] Difference between instream Stations 11 (downstream) and 12 (upstream).

[x] Difference between instream Stations 302 (downstream) and 301 (upstream).

[w] Difference between instream Stations 9 (downstream) and 10 (upstream). Samples were only compared when flow was connective between the stations.

[v] Difference between instream Stations 5 (downstream) and 8 (upstream), which captured runoff from corral area.

[u] Both stations are edge-of-field but not connective; Station 310 was furthest downstream, while Station 311 was about mid-field.

[t] The only BMP that was effectively implemented was for erosion control so the reduced TSS concentration was considered positive.

[s] The 2009 water quality data were not included in the statistical analysis.

[r] A higher quantity of manure was applied in the post- than pre-BMP years, so although TSS increased, the significant decrease in TP was considered successful. The significant increase in NH_3-N may be linked to the change in hog to poultry manure.

[q] Four edge-of-field stations captured runoff from the same field, which was a quarter section in size.

[p] Difference between in-stream Stations 202 (downstream) and 201 (upstream).

[o] High = high-flow period from late-April/early-May to mid-October (i.e., irrigation season).

[n] Low = low-flow period from mid-October to late-April/early-May.

Table 8.4. Percent reduction and post-BMP concentrations during runoff events for the six edge-of-field monitoring stations where BMPs were effective at improving water quality.

BMP site	TN		TP		TSS		*E. coli*	
	Reduction (%)	Post-BMP concentration ($mg\ L^{-1}$)	reduction (%)	Post-BMP concentration ($mg\ L^{-1}$)	reduction (%)	Post-BMP concentration ($mg\ L^{-1}$)	reduction (%)	Post-BMP concentration ($mpn\ 100\ mL^{-1}$)
NMF	31	13.9	32	1.33	nr[z]	71	30	23
WFD	2	14.2	52	0.67	nr	26	nr	251
NFD[y]	49	4.19	25	1.10	50	6	81	2196
LLB[x]	36	6.71	53	1.54	55	18	85	403
BDF[w]	131	6.65	24	3.77	nr[v]	39	56	643
Average	**50**	**9.13**	**37**	**1.68**	**53**	**32**	**63**	**703**

[z] nr = no reduction.

[y] Monitoring Station 310.

[x] Data from 2009 were not included.

[w] Average of monitoring Stations 203, 204, 205, and 206.

[v] Monitoring Station 204 had a reduction of 65%, but the remaining stations had an increase in TSS.

Table 8.5. Average runoff concentrations and standard deviations of total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) for the pre-BMP and post-BMP periods at the outlets of the Indianfarm Creek Watershed and Whelp Creek Sub-watershed.

Period[z]	n	TN		TP		TSS	
		Average[y]	SD	Average	SD	Average	SD
		---------- ($mg\ L^{-1}$) ----------					
		Indianfarm Creek Watershed					
Pre-BMP	47[x]	1.73*b*	1.19	0.20*b*	0.34	122*b*	355
Post-BMP	45[x]	3.47*a*	3.37	0.63*a*	0.61	276*a*	404
		Whelp Creek Sub-watershed					
Pre-BMP	59[x]	2.79*a*	0.92	0.52*b*	0.31	8*b*	9.2
Post-BMP	37[x]	3.32*a*	2.18	0.70*a*	0.47	15*a*	21.5

[z] The pre- and post-BMP periods included data from 2007 to 2009 and from 2010 to 2012 in Indianfarm Creek, respectively. In Whelp Creek, the pre- and post-BMP periods included data from 2008 to 2010 and from 2011 to 2012, respectively.

[y] Averages for each watershed followed by letters are significantly different ($P < 0.1$).

[x] Average concentrations included snowmelt and rainfall data. Base-flow data were omitted.

Table 8.6. Summary of beneficial management practices (BMPs) effects on riparian and rangeland quality.

Riparian Survey Assessment		Rangeland Survey Assessment		Rangeland Production	
Site	**BMP effective**	**Site**	**BMP effective**	**Site**	**BMP effective**
IMP - exclusion[z]	Yes	PST	Yes	PST	Yes
IMP - non-exclusion[y]	Yes - marginal	FLT	Yes	NPS	No
PST - rotational grazing[y]	Yes			SPS	No
WIN - rotational grazing[y]	Yes				
OSW - exclusion[z]	Yes				
OSW - non-exclusion[y]	No				
DUG - exclusion[z]	Yes				
DUG - non-exclusion[y]	No				

[z] Cattle had modified access to the riparian or pasture area during the post -BMP period.
[y] Cattle were excluded from a water body using fences during the post-BMP period.

8.6.4 Cost of BMPs

The cost of implementing and maintaining the BMPs ranged from $466 to $87,770, and labour requirements ranged from 13 to 202 hours (Figure 8.6). Figure 8.6 includes BMP practices as well as bioengineering reclamation work to mitigate stream erosion at two sites (PST-Bio and WIN-Bio).

- The cost of the bioengineering reclamation projects at the PST and WIN sites was relatively high compared the costs of the BMPs implemented at these two sites.
- It can be argued that bioengineering is not a BMP but rather a reclamation practice.
- Without including the cost of the bioengineering at the PST and WIN sites, the average cost was $19,341 and required 46 hours of labour per BMP site.
- The median cost was less for the field nutrient management sites ($5775) compared to the cattle management sites ($9507) (Figure 8.6a).
- The majority of cost was generally a one-time cost to implement the BMP plans.
  - ➢ This involved the construction of fences, relocation of feeding areas and construction of wind breaks, removal of old corrals, and purchase of off-stream watering systems or other equipment.
  - ➢ After the initial implementation, annual maintenance costs were minimal for the remainder of the BMP Project (two to three years).

The BMP costs recorded in the field study were the total costs required to implement the BMP plans. The modelling aspect of this project (Jedrych et al. 2014a,b) provided an economic assessment (cost effectiveness) for BMP scenarios, and this provided a long-term perspective of investments and returns. Jedrych et al. (2014a,b) found that model simulations generally showed a cost associated with environmental improvement through the implementation of BMPs.

There are many barriers to the adoption of BMPs, including cost (Brant 2003; Alberta Research Council 2006). Baird (2012), through the University of Saskatchewan, carried out a survey in the IFC, WHC, and Battersea Drain watersheds and several

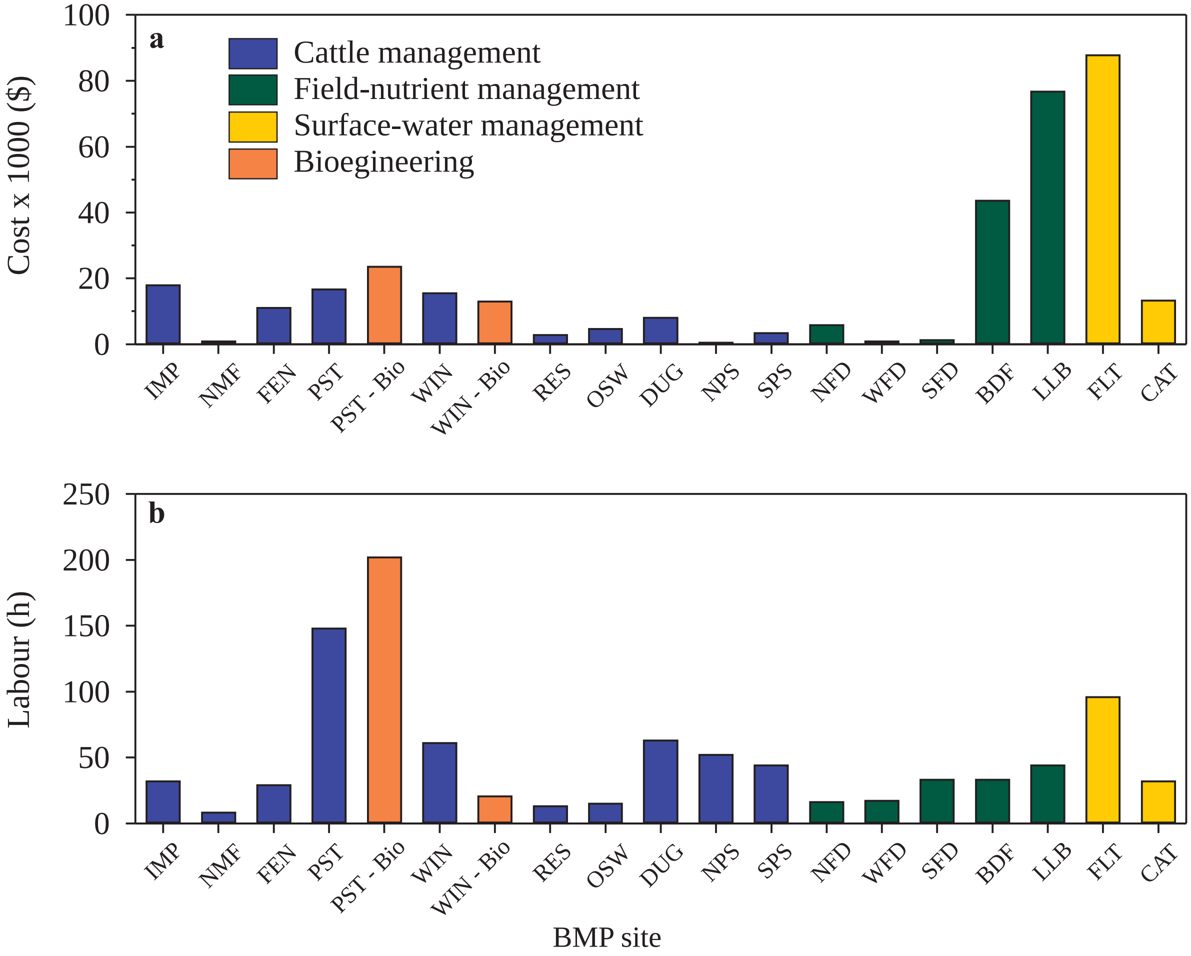


Figure 8.6. Financial costs (a) and labour requirements (b) for beneficial management practices implementation.

other communities in southern Alberta. The sample population included producers, rural residents that were not producers, and urban residents. This survey was part of a study to assess the potential to implement performance-based approaches for water quality management on agricultural landscapes in Canada. Baird (2012) reported that respondents were generally in favour of a combination of polluter pays and beneficiary pays principles. The combination favoured was that polluters pay to meet a minimum standard and that beneficiaries pay above the standard.

8.7 Comparison of Water Quality to other Agricultural Fields

In the Alberta Soil Phosphorus Limits Project (P Limits Project), water quality was examined from eight edge-of-field sites throughout the province from 2003 to 2005 (Little et al. 2006). The P Limits Project sites included a field of native grassland, five non-manured fields, and two heavily manured fields. One of the heavily manured fields was the LLB site, which was also monitored for the BMP Project. Results from the P Limits and BMP projects were examined.

Generally, there was an increase in TN and TP concentrations in runoff as fields were converted from native range to cultivated farmland and as manure applications increased (Figure 8.7).

- The native site (STV) generally had the lowest average TN concentration of about 2.1 mg L^{-1} and TP concentration of 1.0 mg L^{-1}.
- Cultivated crop fields that were not manured had an average TN concentration of 5.8 mg L^{-1} and TP concentration of 0.8 mg L^{-1}.
- Manured sites had an average TN concentration of 14.0 mg L^{-1} and TP concentration of 1.9 mg L^{-1}.
- Heavily manured sites had an average TN concentration of 12.2 mg L^{-1} and TP concentration of 4.9 mg L^{-1}.

At sites where extensive grazing practices occurred (i.e., pasture sites), water quality concentrations tended to be higher than water quality from the native range pasture. For all agricultural fields, the highest TN and TP concentrations tended to be at sites where manure was spread at moderate or heavy rates for crop production.

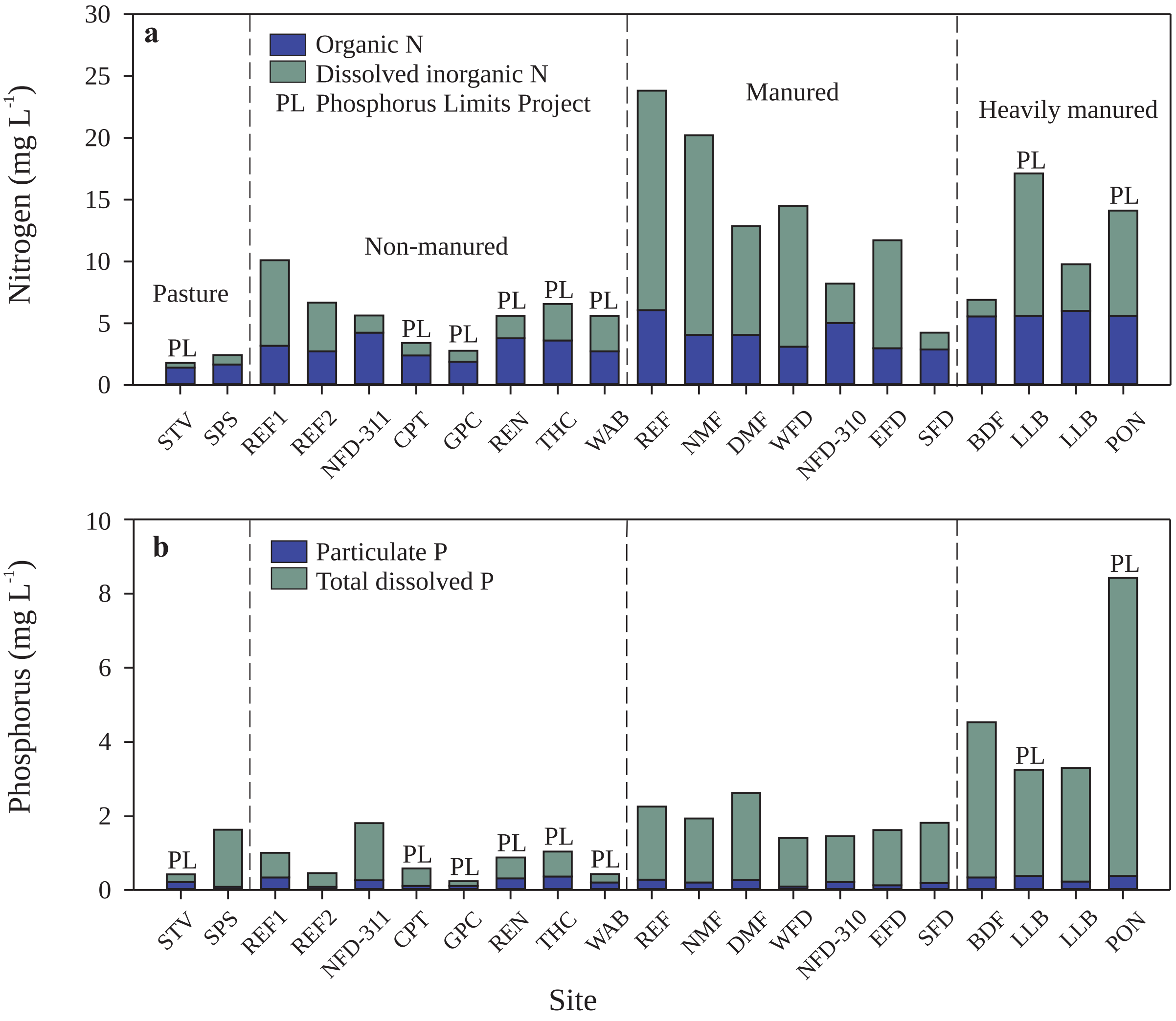


Figure 8.7. Average edge-of-field (a) total nitrogen and (b) total phosphorus concentrations for agricultural fields monitored in the Nutrient Beneficial Management Practices Evaluation Project and the Soil Phosphorus Limits Project.

8.8 Comparison with other Watersheds

There are about 446 watersheds in Alberta where agriculture is the predominant land-use activity (Anderson et al. 1999; Figure 8.8; Table 8.7). These watersheds are within three natural regions:

- The Boreal Forest (Dry Mixedwood Natural Sub-region);
- Parkland; and
- Grassland.

In the BMP Project, the WHC Sub-watershed was representative of the typical high agricultural intensity in the Parkland Natural Region. The IFC Watershed was representative of the Grassland Natural Region, which has 45% of its watersheds classified as moderate agricultural intensity.

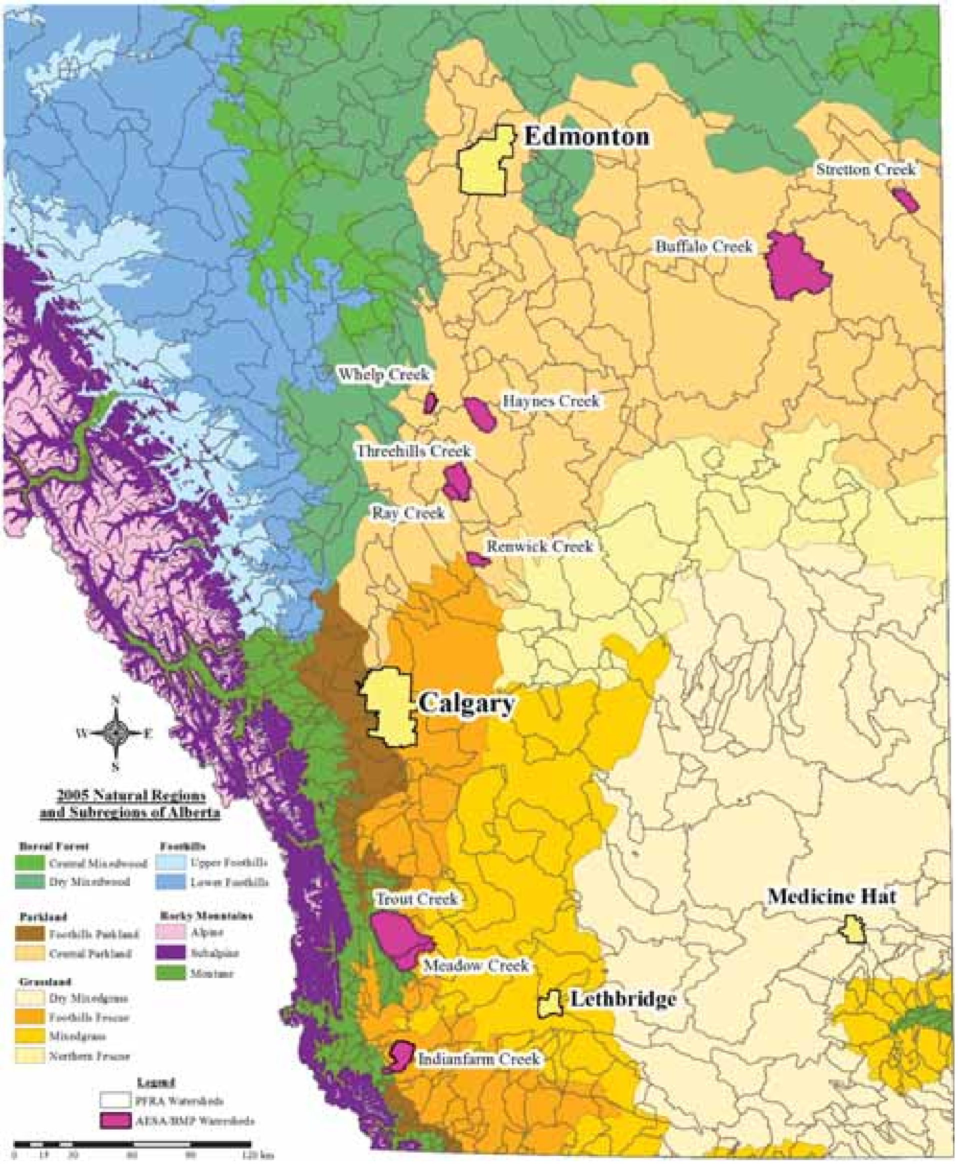


Figure 8.8. Alberta natural regions and Prairie Farm Rehabilitation Administration (PFRA) watersheds.

The irrigated field sites (BDF and LLB) were also in the Grassland Natural Region and the fields were in watersheds with high agricultural intensity.

Watershed size varies among the three natural regions. The Boreal Forest (Dry Mixwood Natural Subregion) tends to have the largest watersheds with an average size of about 93,800 ha followed by the Parkland Natural Region and the Grassland Natural Region (Table 8.7).

From 1999 through 2006, the Alberta Environmental Sustainable Agriculture (AESA) Water Quality Monitoring Project monitored and assessed water quality in 23 small agricultural watersheds throughout Alberta (Palliser Environmental Services Ltd and ARD 2008). The 23 watersheds used in the AESA Water Quality Project (Figure 8.9) ranged in size from 3,200 to 137,000 ha (Lorenz et al. 2008). The BMP Project watersheds are compared with the AESA watersheds to assess the potential to extrapolate the results to other parts of Alberta.

The size of the BMP Project watersheds are within the range of size of the AESA watersheds in the Parkland and Grassland natural regions (Figure 8.8). Concentrations of TN and TP in the BMP Project watersheds were generally high but comparable to the AESA watersheds. In the Grassland watersheds, average TN and TP concentrations were significantly higher at the outlet of IFC when compared to Meadow and Trout creeks, which were part of the AESA study (Figures 8.10a and 8.11a). The WHC Sub-watershed had the second highest TN and TP concentrations in the Parkland Natural Region (Figures 8.10b and 8.11b). The ratios of ON:TN and PP:TP in the BMP Project watersheds were generally comparable to the AESA watersheds in their respective natural regions (Figures 8.10 and 8.11).

Much of the runoff in the Grassland watersheds is driven by spring rains in late May and early June; whereas, runoff in the Parkland watersheds is driven by snowmelt in March and April (Lorenz et al. 2008). Runoff in the BMP Project watersheds generally followed these patterns (Figure 8.12).

Table 8.7. Number of agricultural streams and average watershed size in the Boreal Forest, Parkland, and Grassland natural regions, stratified by agricultural intensity.

Natural region	Number of streams	Average watershed area (ha)	Agricultural intensity		
			High[z]	Moderate	Low
Boreal Forest[y]	116	93,793	20	72	24
Parkland	112	50,829	77	33	2
Grassland[x]	218	43,745	62	99	57
Total	446		159	204	83

[z] Agricultural intensity was based on the relative ranking of the agricultural watersheds based on three variables: chemical expenses (dollars per hectare), fertilizer expenses (dollars per hectare), and manure production (megagrams per hectare) (Anderson et al. 1998; Lorenz et al. 2008).
[y] In the Dry Mixedwood Natural Subregion.
[x] Includes dryland and irrigated watersheds.

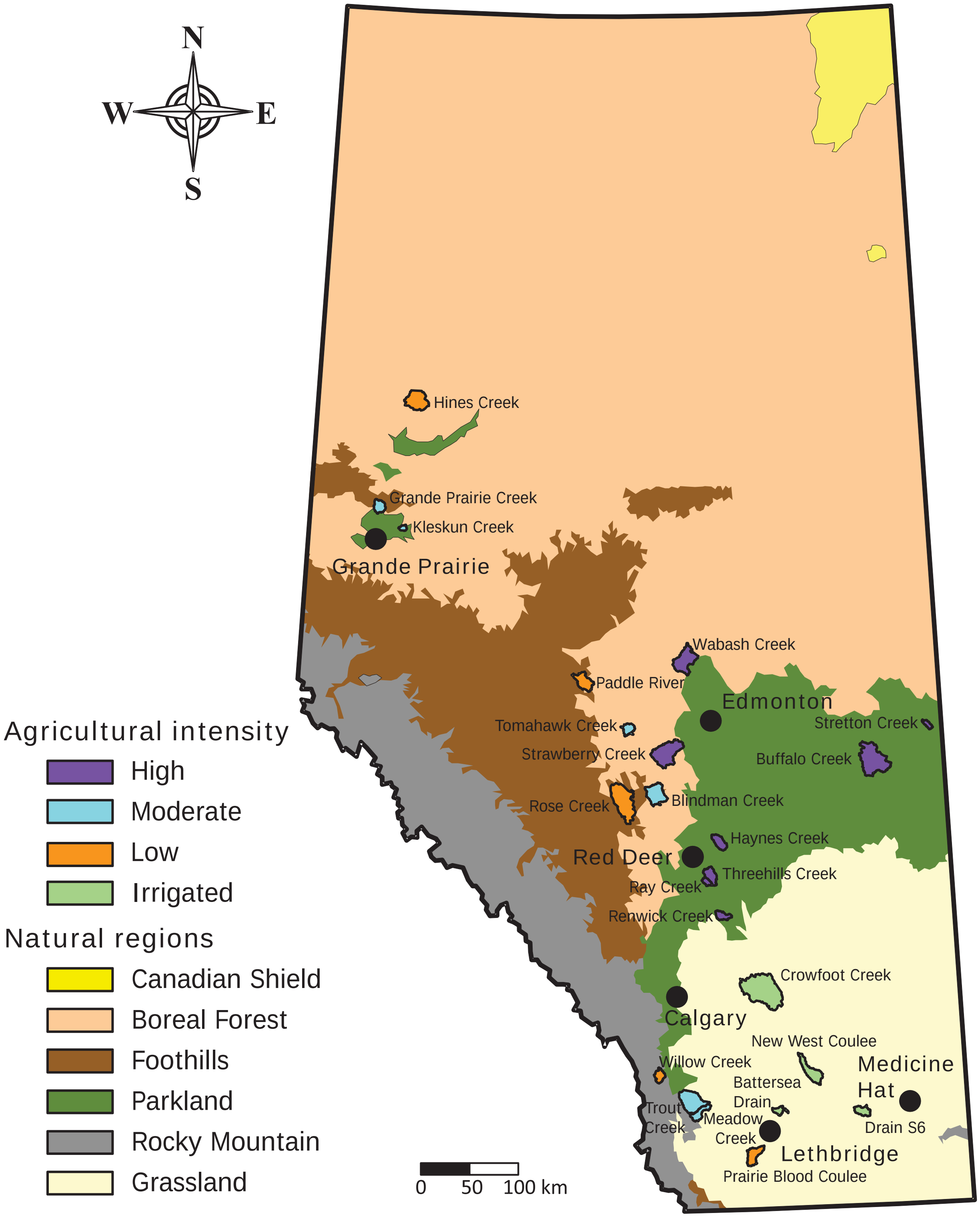


Figure 8.9. Location of Alberta Environmentally Sustainable Agriculture (AESA) Water Quality Monitoring Project watersheds.

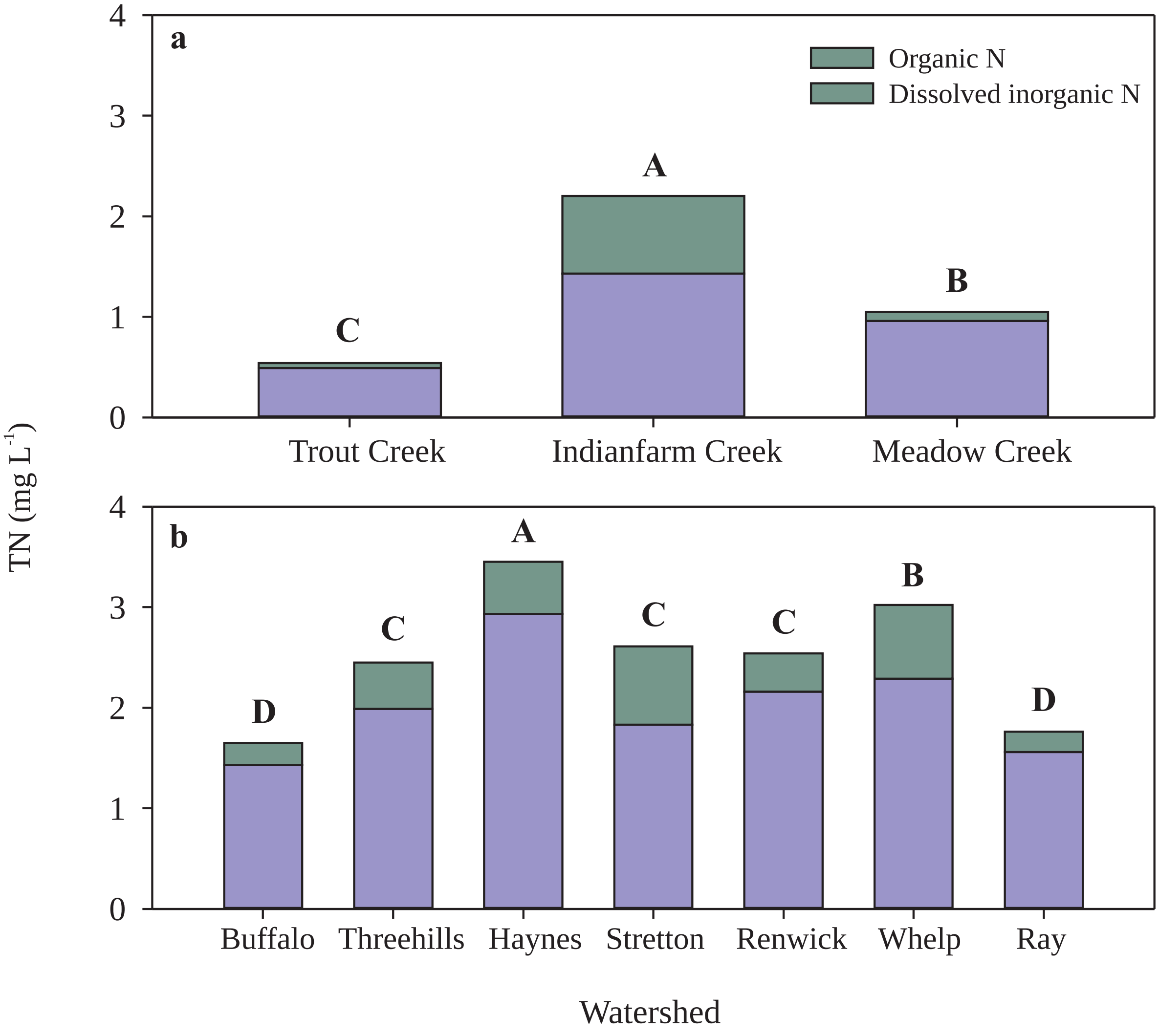


Figure 8.10. Average total nitrogen (TN) concentrations at the outlets for (a) Grassland watersheds and (b) Parkland watersheds. Watersheds are in order of increasing size from left to right. Capitalized letters above bars indicate significant differences in average total concentrations at $P<0.1$.

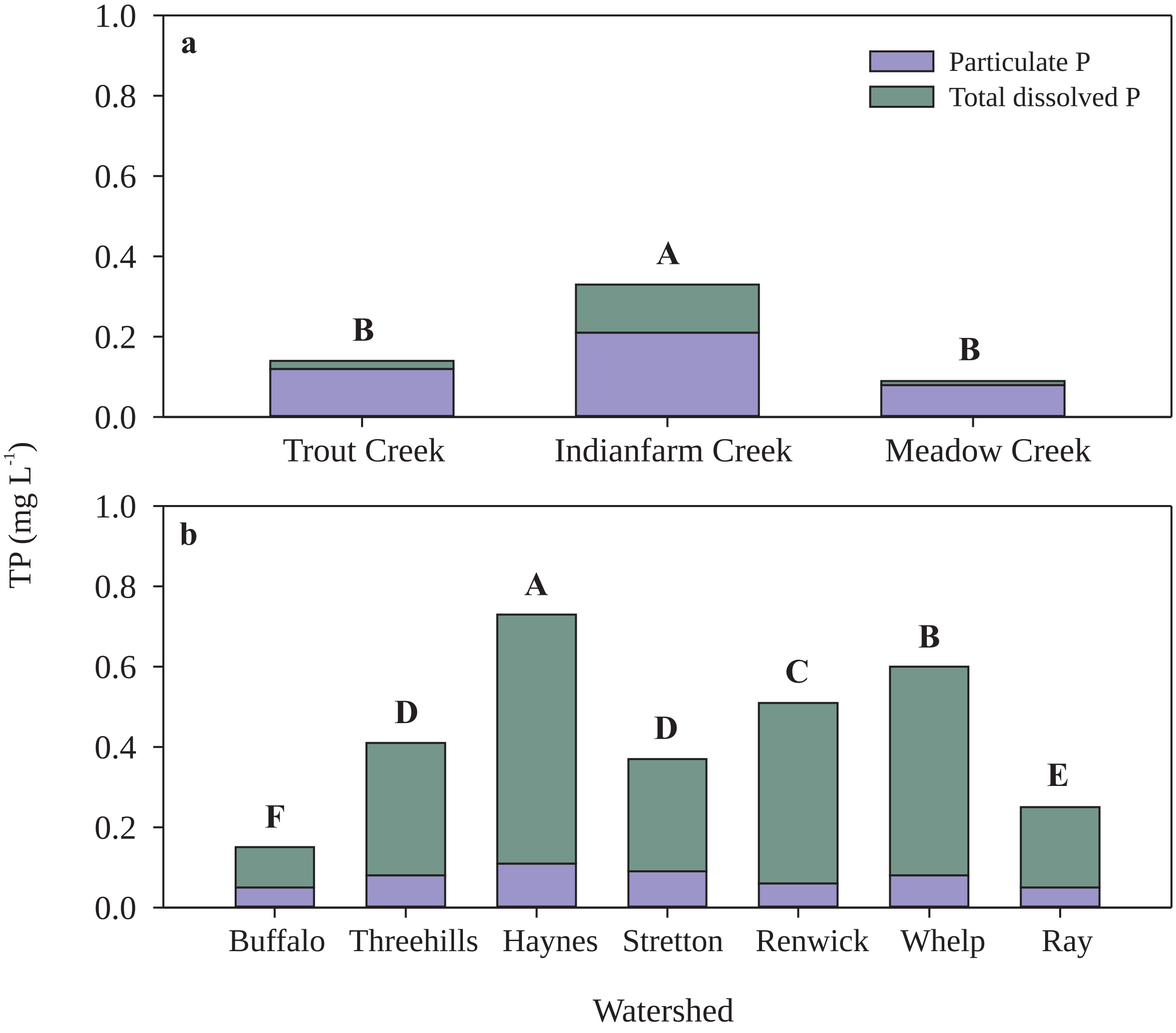


Figure 8.11. Average total phosphorus (TP) concentrations at the outlets for (a) Grassland watersheds with moderate agricultural intensity and (b) Parkland watersheds with high agricultural intensity. Watersheds are in order of increasing size from left to right. Capitalized letters above bars indicate significant differences in average concentrations at *P*<0.1.

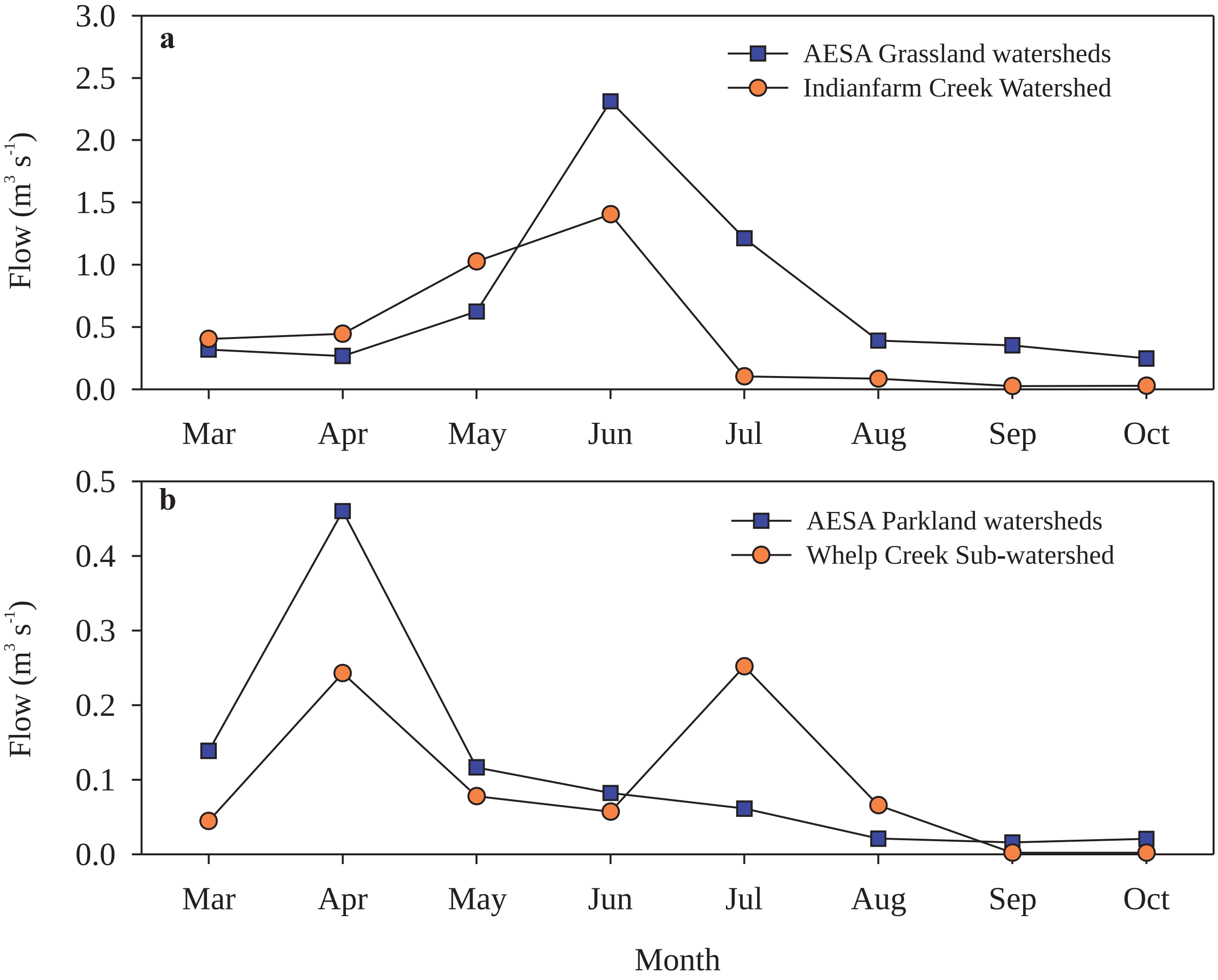


Figure 8.12. Monthly average flows at the outlets of the (a) Alberta Environmentally Sustainable Agriculture (AESA) Grassland watersheds (Meadow and Trout Creeks - 1995 to 2007) and Indianfarm Creek (2007 to 2012), and (b) AESA Parkland watersheds (Buffalo, Threehills, Haynes, Stretton, Renwick, and Ray creeks - 1995 to 2007) and Whelp Creek Sub-watershed (2008 to 2012).

9 CEEOT MODEL APPLICATION TO THE BMP PROJECT WATERSHEDS

9.1 Introduction

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. To extrapolate the key results obtained from the field research to non-monitored fields of the study areas and to other parts of the province, the model Comprehensive Economic and Environmental Optimization Tool (CEEOT) was used. This model was designed to evaluate the economic and environmental effects of agricultural BMPs to improve 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 model was applied to the Indianfarm Creek (IFC) and Whelp Creek (WHC) watersheds, as well as to the Lower Little Bow (LLB) Field. The objectives of the CEEOT modelling component of the BMP Project were to:

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

Alberta Agriculture and Rural Development completed two large-scale modelling studies to examine relationships between land and water quality in Alberta's agricultural watersheds. The studies were the Alberta Soil Phosphorus Limits Project and the Nutrient BMP Evaluation Project.

For the Alberta Soil Phosphorus Limits Project, Jedrych et al. (2006) used a modelling approach to determine STP at the soil polygon scale to meet hypothetical TP concentrations in water at the Prairie Farm Rehabilitation Administration (PFRA) watershed scale (Figure 8.8) in the agriculture region of Alberta. Their approach was to first set a TP water quality objective (0.5 or 1.0 mg L^{-1}) at the watershed outlets and then calculated STP limits in order to achieve the selected water quality objective. They used the Water Erosion Prediction Project model to determine a runoff factor for each watershed and the STP and TP in runoff relationship developed by Little et al. (2006, 2007) to calculate STP values for soil polygons in each watershed. This approach was feasible for P, but would not be feasible for nitrogen, as Casson et al. (2008) found no relationship between soil N and TN in runoff water. Plus, this approach only took into account soil as a source of P.

In the current modelling study, the characteristics of the landscape (baseline or BMP scenario) were used to determine the water quality output at the study area outlet (e.g., TP concentration or export coefficient). This approach, using CEEOT, simulated the amount of improvement in water quality with the application of different BMPs. If a certain output value (i.e., water quality objective) is desired, this approach can simulate the extent of BMPs required, or determine whether the selected water quality objective can be achieved through a reasonable or practical level of BMP adoption, and which BMPs are likely more effective. The CEEOT model also has an economic assessment component. In comparison to the approach Jedrych et al. (2006) used to calculate P limits, the CEEOT model is more comprehensive and robust at simulating the effects of landscape factors and management practices on water quality.

9.2 Model Development

Environmental data for SWAT and APEX were derived from the BMP Project as well as from a variety of other databases. Data entry included water quality and quantity, livestock inventory, topography, land management, soil physical and chemical properties, climate, and hydrology. The APEX and SWAT models were integrated into the SWAPP (SWAT/APEX Program) module of the program to provide reliable simulation of detailed field processes and still take advantage of the large watershed routing capabilities of SWAT (Figure 9.1) (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.

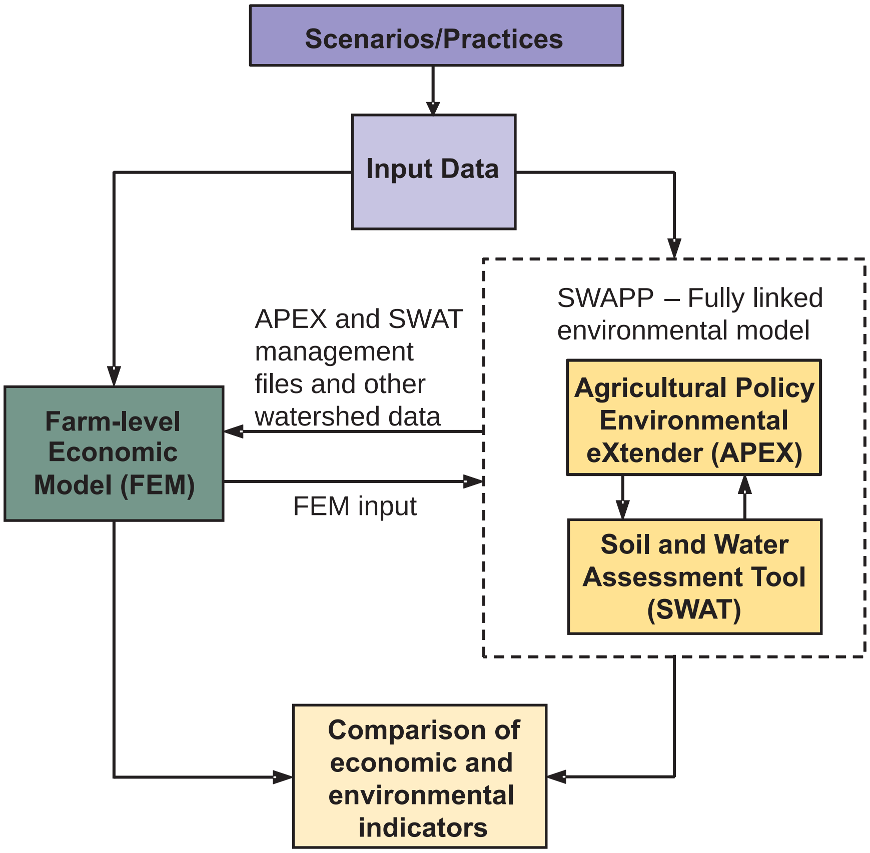


Figure 9.1. Schematic of the CEEOT modelling system.

The mean monthly flows and sediment and nutrient losses obtained from the calibrated SWAPP were compared with measured values (2007 to 2010) from the two watersheds and the LLB site to assess model performance. The IFC and WHC calibration results showed that SWAPP produced reasonably good predictions of runoff, TSS, N, and P losses at the watershed outlets. However, SWAPP predictions were less accurate at the field-scale, where flow was very low.

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

9.3 Scenario Evaluation

In total, five scenarios were evaluated for either a 30- (IFC and WHC) or 35-year (LLB) period of CEEOT simulations (Table 9.1).

- **Scenario 1 – Baseline.** The baseline (status quo) scenario included distribution of the existing farm management practices prior to BMP implementation. The farm survey indicated that most producers generally complied with the *Alberta Agricultural Operation Practices Act* (AOPA).
- **Scenario 2 – Field Study.** For this scenario most of the land base within the IFC and WHC watersheds had the same management practices as in Scenario 1 except for the few sites where the Field Study BMPs were implemented.
- **Scenario 3 – AOPA.** This Act includes regulation for manure application to fields (Province of Alberta 2010). The baseline scenario included AOPA standards, as the regulations were enforced at the time. This scenario evaluated AOPA regulations considered the most environmentally ideal, regardless of practicality or ability of the farmer to implement them.

Scenarios 1 to 3 included a number of practices that were considered to be relevant for each watershed and addressed four main concerns:

a) Manure management;
b) Livestock management;
c) Erosion control; and
d) Irrigation efficiency and runoff.

Table 9.1. Scenarios simulated in the CEEOT model for the Indianfarm Creek Watershed (IFC), Whelp Creek Sub-watershed (WHC), and Lower Little Bow Field (LLB).[z]

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
IFC	1 (Baseline)														
	2 (Field Study)	X													
	3 (AOPA)		X	X	X	X									
	4 (Cow-calf)		X	X	X	X			X	X	X	X			
	5 (P-limit)		X	X	X		X	X	X	X	X	X			
WHC	1 (Baseline)														
	2 (Field Study)	X													
	3 (AOPA)		X	X	X	X									
	4 (P-limit)		X	X	X		X	X							
	5 (Riparian)		X	X	X		X	X			X	X	X	X	
LLB	1 (Baseline)														
	2 (Field Study)	X													
	3 (AOPA)		X	X	X	X									
	4 (P-limit)		X	X	X		X					X			
	5 (Irrigation)		X	X	X		X					X			X

Scenarios 1 to 3 were similar among the watersheds; whereas, Scenarios 4 and 5 differed among the watersheds to reflect targeted concerns specific to each watershed.

- **Scenario 4 – Cow-calf (IFC) and P-limits (WHC and LLB).** For WHC, Scenario 4 (P-limits) included certain aspects of Scenario 3. For IFC, Scenario 4 (cow-calf) included Scenario 3 plus the following four cow-calf and riparian management practices:

- **Cattle restrictions.** Cattle access to streams, creeks, or other water bodies was restricted;
- **Rotational grazing.** Rotational grazing was applied to cattle pastures when required for the specific scenario;
- **Vegetative buffer strips.** Buffer strips were placed on a portion of the field adjoining dugouts, wetlands, and other water bodies other than streams; and
- **Grassed waterways.** Drainage channels within cultivated fields were converted to simulated 15-m wide permanent grass cover.

- **Scenario 5 – P-limit (IFC), Riparian (WHC), and Irrigation (LLB).**
  - For the IFC Watershed, Scenario 5 (P-limit) included all of the features of Scenario 4 in addition to manure application based on P uptake rate of crops and no manure application in the fall or winter.
  - For the WHC Sub-watershed, Scenario 5 augmented Scenario 4 with riparian management practices, restrictions on fall tillage, as well as wetland restoration.
  - For the LLB site, Scenario 5 (irrigation) included Scenario 4 plus automated irrigation scheduling and irrigation restrictions in critical runoff source areas.

The environmental indicators of runoff depth and the loss of sediment (total suspended solids) and nutrients (TN and TP) were chosen to assess the scenario results.

9.4 Results and Discussion

The results of the model simulations showed that the BMP scenario performance was site and watershed specific, and confirmed several conclusions from the field study.

Scenario 2 (Field Study BMPs). This scenario did not result in large water quality improvements at the watershed outlets. This reflected the few BMPs that were implemented in the watersheds relative to the land base of the watersheds. In contrast, at the edge-of-field, the model indicated that significant water quality improvements would occur by the implementation of the BMPs.

Scenario 3 (AOPA). This scenario was only slightly more effective at improving water quality than Scenario 2 compared to Scenario 1 (baseline). The small improvement was because of manure application setbacks in Scenario 3. Another finding related to AOPA was that the soil NO_3-N limits were largely unbinding in effect because most soils in the two watersheds were less than the thresholds given in AOPA during the 30- or 35-year simulation horizon.

Scenario 4. The addition of cow-calf and riparian BMPs in IFC (Table 9.2) resulted in the largest environmental gains and was also the most cost effective scenario. The agronomic P limit in Scenario 4 of WHC (Table 9.3) resulted in some improvement in comparison to the AOPA NO_3-N limit in Scenario 3.

Scenario 5. Adding an agronomic P limit had little impact over Scenario 4, as there were less than six fields in IFC that had manure applied. However, it was the buffer strips, grassed waterways, and wetland restoration in Scenario 5 that showed the greatest environmental improvements in WHC, albeit at a fairly significant cost.

Table 9.2. Average annual environmental and economic results based on 30-year simulation at the outlet of Indianfarm Creek Watershed for different scenarios.

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

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

[y] Differences for Scenarios 2 to 5 are expressed relative to Scenario 1 (baseline). Negative numbers indicate a decrease compared to the baseline.

Table 9.3. Average annual environmental and economic results based on 30-year simulation at the outlet of the Whelp Creek Sub-watershed for different scenarios.

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

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

[y] Differences for Scenarios 2 to 5 are expressed relative to Scenario 1 (baseline). Negative values indicate a decrease compared to the baseline.

For the LLB site, the Scenario 2 simulation resulted in a moderate to large reduction in the environmental indicators compared to the baseline. Total N was reduced by 85% and TP was reduced by 56% (Table 9.4), and most of these predicted reductions were in soluble forms (NO_3-N and PO_4-P).

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

Additional observations from the model results showed:

- Riparian and cow-calf BMPs that involved structural controls such as off-stream watering, setbacks, buffer strips, fencing, and grass waterways resulted in significant reductions in sediment and nutrient losses.
- Phosphorus-based manure application limits were shown to be expensive to implement. In the P-based manure application scenarios, reduction of TP in the runoff was greater at the edge-of-field site than at the watershed outlets.
- All BMP scenarios resulted in negative net returns either from a decline in revenues or an increase in cost. The size of the representative farms affected the scale of the economic impact when they were reported on a per hectare basis.

Table 9.4. Annual average and economic results based on 35-year simulation at the outlet of the Lower Little Bow Field under different scenario model simulations.

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

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

[y] Differences for Scenarios 2 to 5 are expressed relative to Scenario 1 (baseline).

9.5 Future Application of CEEOT in Alberta

- Very low flows were often well below the predictive ability of the simulation models used in this study.
- A significant amount of time was dedicated to improve SWAPP calibration results at the field-scale and watershed outlets. However, the final predictions of sediment and nutrient losses at this very detailed scale were not accurate enough to justify the time spent performing such refined calibrations at the field scale.
- Based on the experience gained from the SWAPP calibrations, it is recommended that future work be conducted for watershed outlets or sub-basin outlets with contributing areas at least the size of the WHC or IFC watersheds.
- It is anticipated that future CEEOT applications in other Alberta watersheds will require less effort and data collection than the BMP Project.
- Based on an inventory of the existing Alberta databases, the majority of the data are readily available at the different scales and formats required for the CEEOT model.

10 CEEOT MODEL APPLICATION TO THE RED DEER RIVER WATERSHED

10.1 Introduction

A key component of the BMP Project was the extrapolation of the field-site BMPs to a larger watershed to:

- Assess the potential effectiveness of the recommended BMPs to mitigate agricultural impacts on water quality in a watershed; and
- Assess the scale of BMP requirements to achieve acceptable watershed mitigation.

For this project, several BMPs in the Indianfarm and Whelp Creek watersheds were evaluated using CEEOT (Jedrych et al. 2014a; Chapter 9), which was then applied to a portion of the Red Deer River (RDR) Watershed (Figures 10.1) in central Alberta. The study area selected within the watershed (RDR study area) was approximately 1.2 million ha, stretching from the City of Red Deer to the Town of Drumheller (Figure 10.1). 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. 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 sub-regions of Alberta. Most of the RDR study area was in the Central Parkland Natural Sub-region. The remaining portions of the study area were in the Lower Foothills, Central Mixedwood, Dry Mixedwood, Foothills Fescue, and Northern Fescue natural sub-regions.

The RDR study area was selected, in part, because water quality in five sub-basins were monitored 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. In addition, three Alberta Environment and Sustainable Resource Development long-term water quality monitoring sites were located along the reach of the Red Deer River within the study area.

The objectives of this modelling study were to:

- Evaluate CEEOT performance at AESA sub-basin and RDR study area scales;
- Estimate export of nutrient loads (TP and TN) and TSS from the RDR study area and its tributaries;
- Evaluate the relative contribution of large-scale agricultural practices on water quality;
- 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 RDR study area.

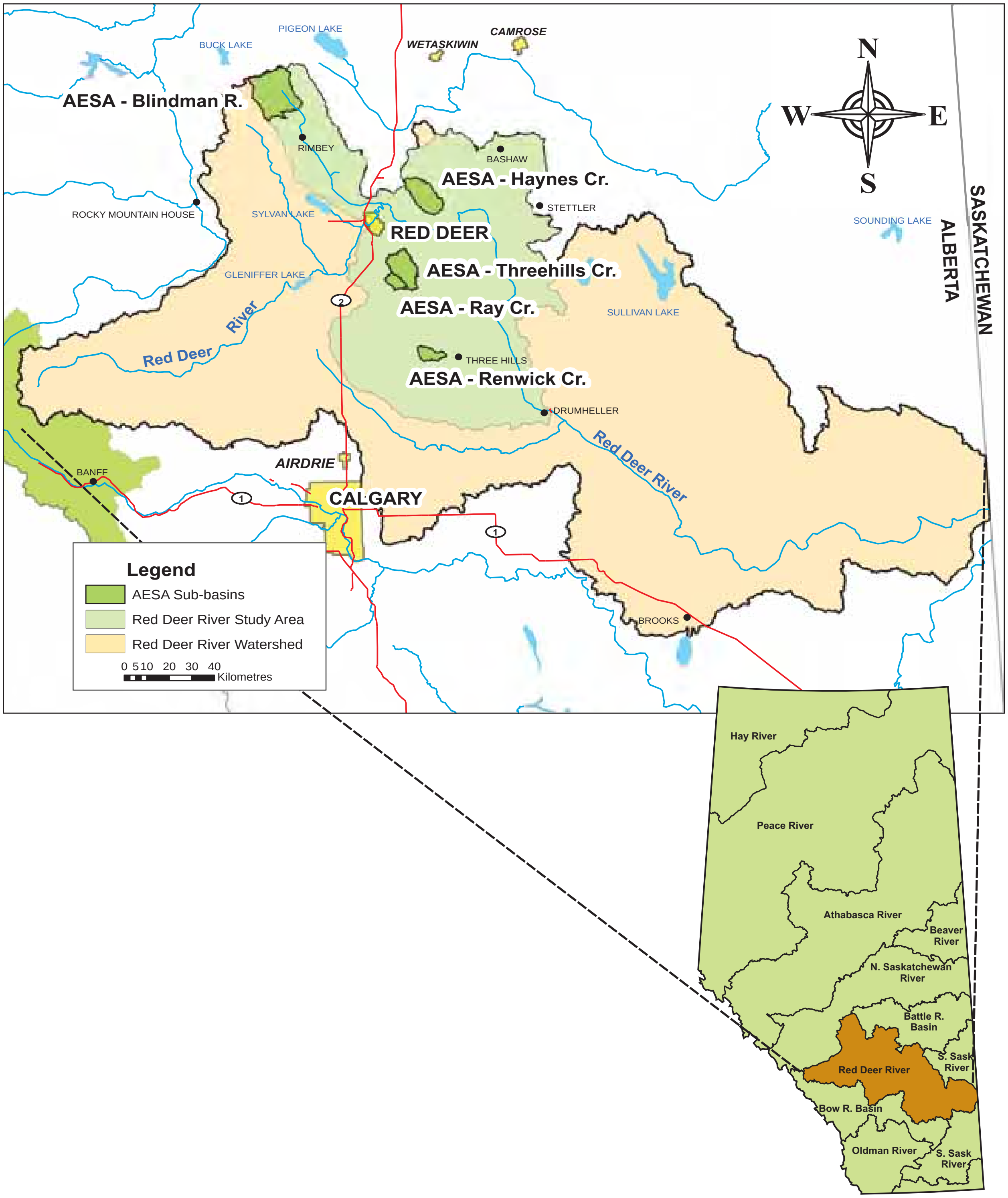


Figure 10.1. Red Deer River Watershed and study area including five Alberta Environmentally Sustainable Agriculture watersheds.

10.2 Model Development

Digital Elevation Model (DEM) data were was used to calculate watershed characteristics such as sub-basin drainage area, slope length and steepness, and stream geometry using an ArcGIS interface. The RDR study area was subdivided into 41 sub-basins (Figure 10.2). The ArcGIS analyses of the DEM data showed surface elevations (Figure 10.3a), soil texture (Figure 10.3b), land use (Figure 10.3c), and monitoring station locations (Figure 10.3d) for the selected portion of the RDR study area.

Agriculture is the main land use in the modelled RDR study area (Figure 10.3c, Table 10.1) and includes annual cropland (44.2%) and perennial cropland and pasture (49.3%).

10.3 BMP Scenario Modelling

Beneficial management practice scenarios were simulated using the calibrated CEEOT model to simulate the economic and environmental impacts of these practices in the RDR study area. The environmental impacts were restricted to water flow and water quality indicators, including sediment and nutrient loads at the outlets of the five selected AESA sub-basins and the RDR study area. Economic impacts were determined using typical farm enterprise cost and return indicators.

In total, seven BMP simulation scenarios were developed for the study (Table 10.2).

- **Scenario 1 – Baseline.** The baseline (status quo) scenario assumed that all producers were in compliance with current Alberta Agricultural Operation Practices Act (AOPA) regulations prior to the implementation of the additional BMP scenarios. Key AOPA requirements include:
    - Manure application is based on NO_3-N concentration limits in the top 60 cm of soil.
    - Manure is incorporated within 48 hours of application.
    - No winter application on snow covered or frozen soil without prior approval.
    - Setbacks from common bodies of water are required for fields that receive manure.

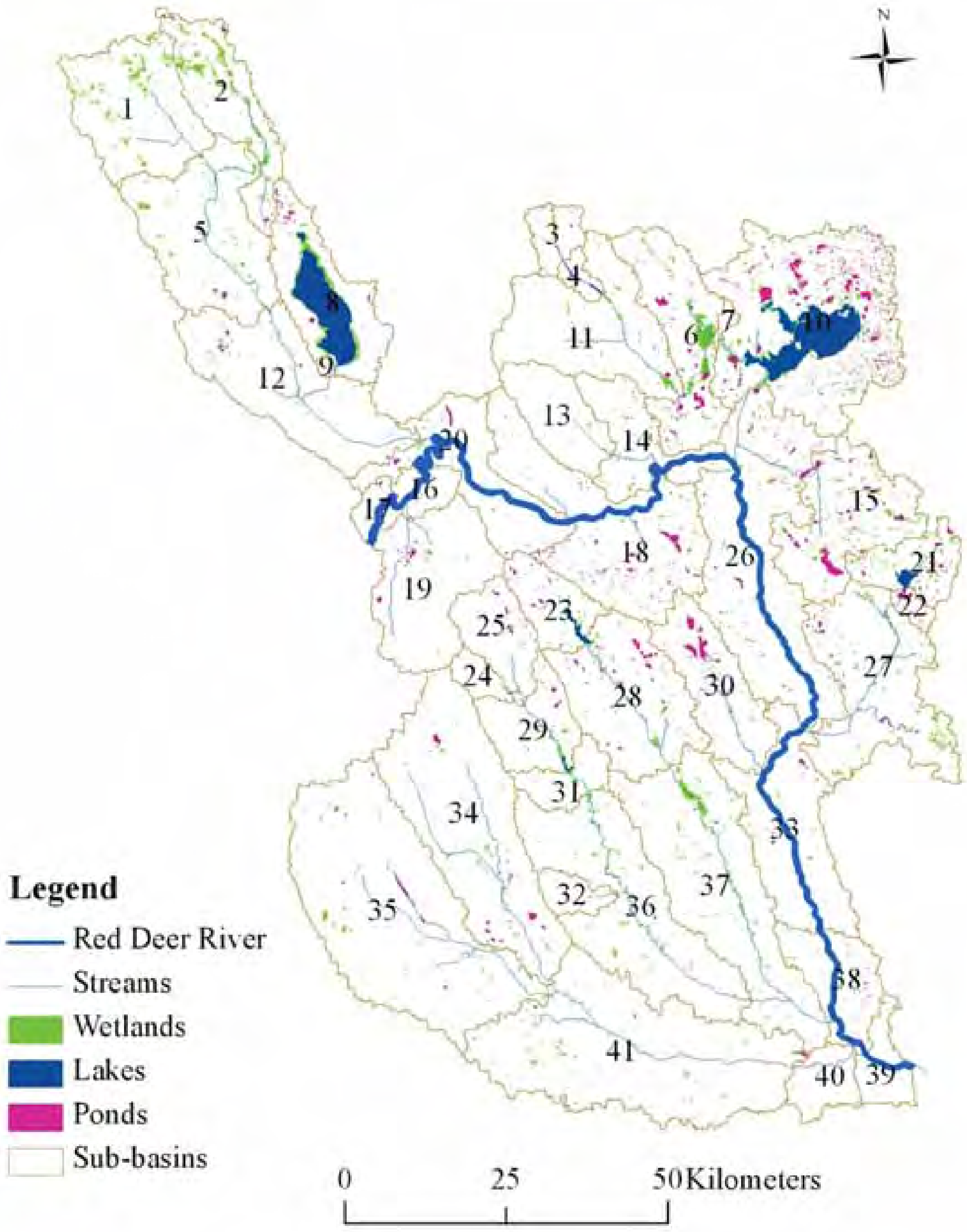


Figure 10.2. Distribution of sub-basins, streams, wetlands, lakes, and ponds within the Red Deer River study area.

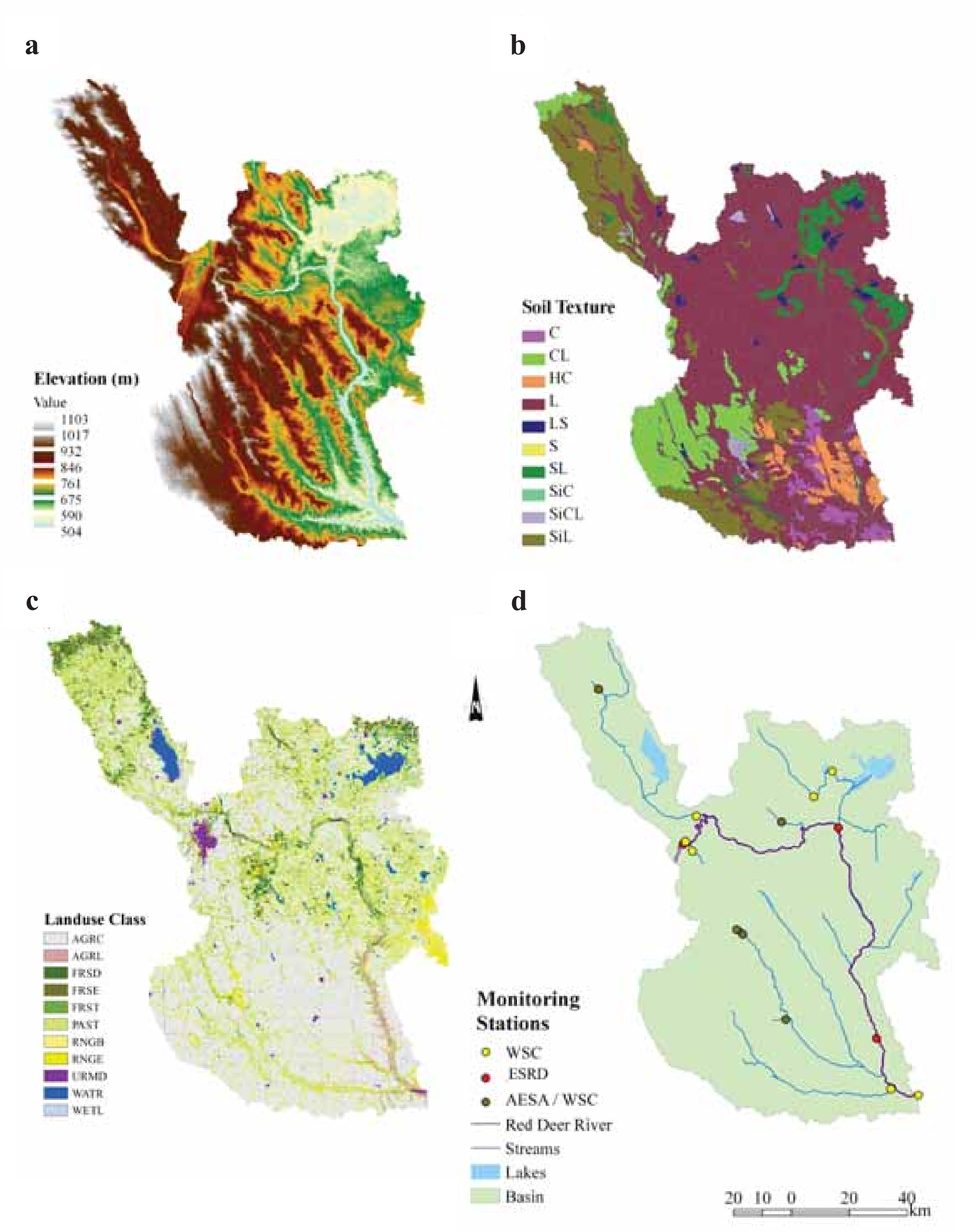


Figure 10.3. Maps of Red Deer River study area selected for CEEOT application showing distribution of (a) elevation, (b) soil texture, (c) land use, and (d) monitoring stations.

Table 10.1. Summary of land-use categories in the Red Deer River study area (2000 Landsat imagery).

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
Spring barley	BARL	219,533	18.0
Spring 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 10.2. Beneficial management practices scenarios used for CEEOT simulation of the Red Deer River study area.

Scenarios	Beneficial management practices								
	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[z]									
2. Manure P 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] Producers are in compliance with the current Alberta Agricultural Operation Practices Act (AOPA) regulations.

- **Scenario 2 – Manure Agronomic Phosphorus Management.** Manure application was based on agronomic P requirements. It was assumed that STP will not change since the amount of P added should match the amount of P removed by the crop. It was also assumed that if manure cannot be applied on a field due to excessive STP, it would be applied on adjacent lands in the sub-basin.
- **Scenario 3 – Rotational Grazing and Controlled Access.** Rotational grazing was simulated on all grazed pastures; whereas, the baseline scenario assumes open access grazing.
- **Scenario 4 – Seasonal Bedding and Feeding Sites.** For this scenario, two BMPs were implemented that would be expected to reduce environmental impacts from cattle bedding and feeding sites near waterways. The BMPs included:
    - ➢ Excluding cattle from riparian areas in winter months; and
    - ➢ Establishing wintering/bedding site setbacks a minimum of 100 m away from waterways.
- **Scenario 5 – Grassed Waterways.** Involved application of 15-m wide grassed waterways in the middle of grain/oilseed fields. It was assumed that all flow from the upland areas of the field would run through the waterway prior to leaving the field. It also assumed that grassed waterways were only necessary on the fields where sediment losses were significant. Based on this assumption, more than 18% of the total drainage area within the RDR study areas was selected for grassed waterway implementation.
- **Scenario 6 – Riparian Setbacks.** Buffer strips (riparian setbacks), 15 m wide, were implemented in all subareas that were adjacent to streams to filter sediments, reduce runoff flow velocity, and reduce edge-of-field erosion. The application of setbacks involved the following management practices.
    - ➢ No manure or fertilizer application, no cropping activity, and no access by livestock in the setback area.
    - ➢ No agricultural production within the setback:
        - ◆ Existing grain/oilseed areas in setback were seeded to grass;
        - ◆ Forages in setback area was left idle; and
        - ◆ Existing pastures required installation of a fence to prevent grazing in the setback area.
- **Scenario 7 – Wetland Restoration.** Scenario 7 involved restoration of previously drained wetlands.

10.4 Results and Discussion

A comparison of the baseline watershed simulation results showed high variability in the cumulative average annual runoff and average annual TSS and nutrient export coefficients among sub-basins. At the RDR study area outlet, the TSS export coefficient was estimated at 0.25 Mg ha^{-1}, the TN export coefficient was 0.22 kg ha^{-1}, and TP export coefficient was 0.20 kg ha^{-1}. These export coefficient values represent the RDR study area plus the area of the RDR Watershed upstream of the study area (Figure 10.1).

10.4.1 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. Due to manure transfers, some areas received more and others received less manure nutrients in Scenario 2 than in the baseline scenario. However, areas that received more manure nutrients received less inorganic fertilizer. The TP export coefficient was reduced from baseline levels by 28.2% at the RDR outlet.

The lower manure application rates resulted in reduced vegetation cover and reduced protection of the soil surface by manure solids. Consequently, the TSS export coefficient increased slightly at the RDR outlet (0.2%). The TN export coefficient was reduced by only 3.5%, possibly as the result of increased supplemental N fertilizer applications on most fields with the reduced manure nutrient rates.

For the RDR study area, the model predicted that Scenario 2 would save farmers on average about \$0.42 ha^{-1} yr^{-1} (Table 10.3). The results varied 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. The cost savings for the small farms was expected because smaller farms usually have more land per animal unit than larger farms, and more land to utilize manure nutrients.

10.4.2 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, and this increased pasture biomass and quality and reduced feed costs. Simulated improvement in pasture conditions were accompanied by reductions in flow, and in TSS and nutrient losses in the majority of

Table 10.3. Change 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

the sub-basins. Improved pasture conditions primarily imply an 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. The TP export coefficient was reduced from baseline levels by 12.5% at the RDR study area outlet, and the TN export coefficient was reduced by 3.8%, which was about the same as Scenario 2. The TSS decreased by 1.2% from baseline levels.

Results from FEM simulations showed an overall net financial gain for farms that implement rotational grazing. 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 (Table 10.4). 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.

Small and medium size farms incurred most of the benefit from rotational grazing, while larger farms were not significantly impacted (Table 10.4). This difference in impact among farm sizes 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.

10.4.3 Scenario 4 – Seasonal Bedding and Feeding

The environmental results of the seasonal bedding scenario were very similar to those of the rotational grazing scenario. Moving cattle away from the stream with a well maintained grass field between the new

Table 10.4. Change 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

seasonal bedding site and the stream resulted in reductions in TSS and nutrient export coefficients. However, the magnitudes of the reductions were somewhat smaller than those predicted for the rotational grazing scenario. The cumulative results at the RDR study area outlet were reductions in TSS of about 1%, and TN and TP export coefficient reductions of 3.1 and 8.2%, respectively.

Average farm-level economic impact for Scenario 4 (Table 10.5) was a relatively small cost (\$0.44 $ha^{-1} yr^{-1}$) for all farms. The small reduction in net returns were caused by increased fencing costs to keep the livestock in upstream bedding areas and the one-time expense of establishing new bedding sites and moving the cattle.

10.4.4 Scenario 5 – Grassed Waterways

Grassed waterways were simulated only for fields where soil losses were relatively significant. As a result, only a small percentage of subareas were simulated with grass. There were reductions in edge-of-field (subarea) indicators wherever the grassed waterways were simulated.

The cumulative impacts from simulation at the RDR study area outlet were generally small reductions. Impacts on TSS and nutrient export coefficients at the outlet were about a 0.5% reduction in TSS, and 2.4 and 3.3% reductions in TN and TP export coefficients, respectively, relative to the baseline.

The model predicted a reduction in net returns, with an average reduction of nearly \$3 $ha^{-1}yr^{-1}$ for the entire RDR study area (Table 10.6). 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 10.5. Change in annual net returns for Scenario 4 (seasonal bedding and feeding) relative to the baseline scenario.

		Average farm 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

Table 10.6. Change in annual net returns for Scenario 5 (grassed waterways) relative to the baseline scenario.

		Average farm 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

10.4.5 Scenario 6 – Riparian Setbacks

Riparian setbacks were only simulated for riparian subareas 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 due to the significant variations in the proportion of each sub-basin that was simulated with riparian setbacks. The cumulative reductions of TSS and nutrient export coefficients at the RDR study area outlet showed a reduction in TSS export coefficient of 1.6%, and a reduction in TN and TP export coefficients of 8.1 and 17.1%, respectively, compared to the baseline. Though similar in magnitude to the reductions predicted for Scenario 3, the reductions for Scenario 6 were slightly greater than for Scenarios 3. Scenario 6 resulted in a predicted cost (Table 10.7) of approximately $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.

10.4.6 Scenario 7 – Wetland Restoration

The model predicted that wetland restoration resulted in a small to moderate reduction in TSS and nutrient export coefficients. 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; and subarea routing sequence assumed for the wetland scenario. The cumulative results at the basin outlet showed a reduction of about 0.5% for TSS, and 1.8 and 3.8%, respectively, in TN and TP export coefficients compared to the baseline scenario.

Table 10.7. Change in annual net returns for Scenario 6 (riparian setbacks) relative to the baseline scenario.

		Average farm 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

Scenario 7 resulted in a reduction in net returns (Table 10.8), 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.

10.4.7 Summary of Scenario Impacts on Nutrient Export

Figure 10.4 shows the relative changes in TN and TP export coefficients for each of the BMP scenarios, relative to the baseline scenario, modelled for the RDR study area. None of the individual BMP scenarios reduced TN to a large extent, and only Scenario 2 (manure P management) reduced TP by about 28%.

It is clear that no single BMP scenario likely exists that will significantly reduce TN and TP export coefficients. Even implementing all of the BMP scenarios in the RDR study area would potentially reduce TN export coefficients by only about 23% and TP export coefficients by about 73% (Figure 10.4). Further analyses will be required to assess the impact of these reductions on the water quality in the receiving streams and tributaries.

10.4.8 Cost Effectiveness of BMP Scenarios

Figure 10.5 provides a graphical representation of the environmental and economic impacts of proposed BMPs and

Table 10.8. Change annual net returns for Scenario 7 (wetland restoration) relative to the baseline scenario.

		Average farm size (ha)	Total net return ($ yr^{-1})	Total net return ($ ha^{-1} yr^{-1})
Red Deer River basin		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

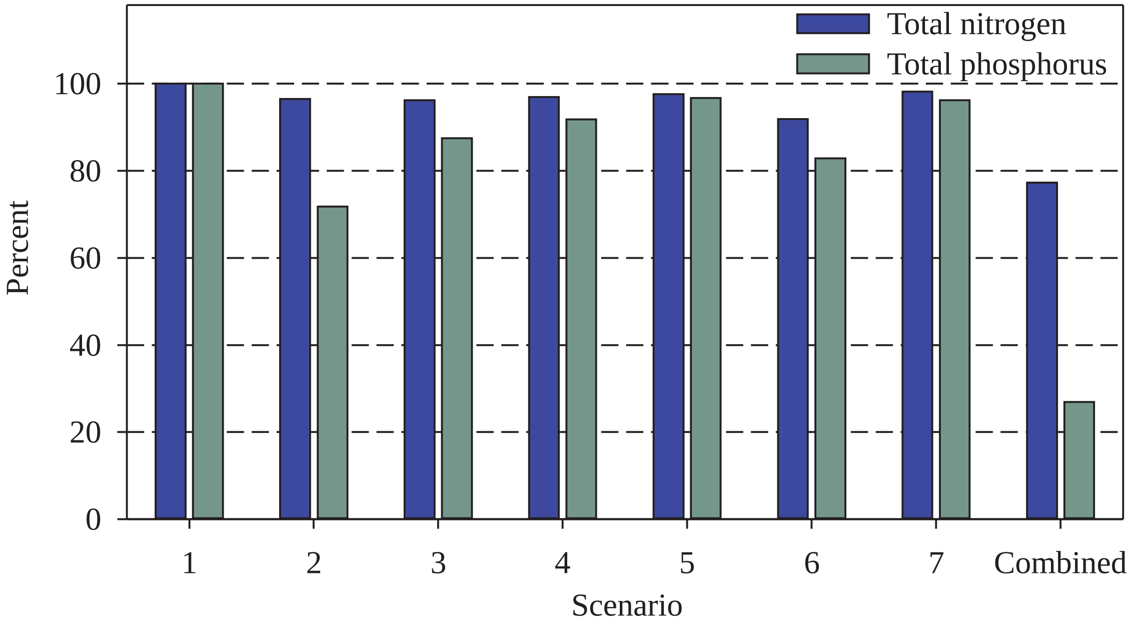


Figure 10.4. Relative changes in total nitrogen and total phosphorus export coefficients for Scenarios 2 to 7 individually and combined compared to the baseline (Scenario 1) at the Red Deer River study area outlet. Baseline values are 0.22 kg ha^{-1} for total nitrogen and 0.20 kg ha^{-1} for total phosphorus.

shows the trade-offs between environmental improvements (E) and changes in farm profits ($). 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 farm profits for the selected scenario. Similarly, regions above the horizontal axis represent percentage increases in an environmental indicator, while regions below the horizontal axis represent percentage reductions (or improvements) in the environmental indicator. A scenario is superior to another if it lies below and to the right of the other. For example, in Figure 10.5, Scenario D is superior to the other three scenarios.

For the RDR study area, graphical comparisons of environmental indicator (runoff depth, TSS, TN, and TP) and farm profit changes relative to baseline conditions are shown in Figure 10.6.

- Scenario 3 (rotational grazing) was the only scenario that showed an improvement in environmental quality (i.e., reduced concentration) combined with increased farm profits.
- Scenario 2 (manure P management) was also positive for TN and TP, but with less profit gain than Scenario 3.
  - ➢ Scenario 2 showed a reduction of about 28% in TP at the outlet of the RDR study area, and a $0.42 ha^{-1} yr^{-1} farm profit.
  - ➢ While adopting a P-based manure management plan will increase costs required to haul manure a greater distance, the increased benefits will yield a small economic benefit basin-wide.

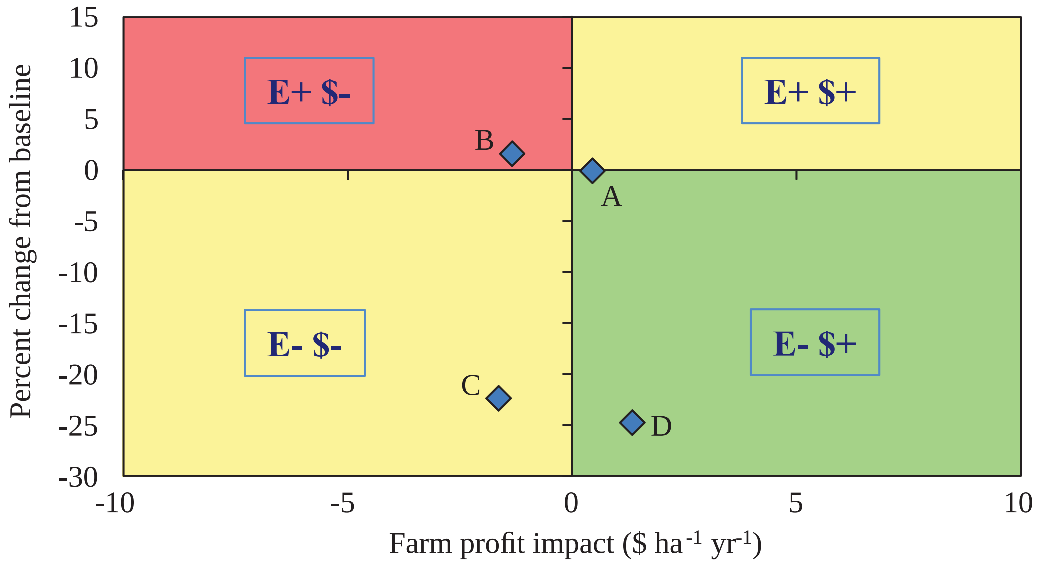


Figure 10.5. Schematic of the CEEOT model output showing environmental (E) and economic ($) impacts of simulated scenarios, where A, B, C, and D each represent a scenario of beneficial management practices.

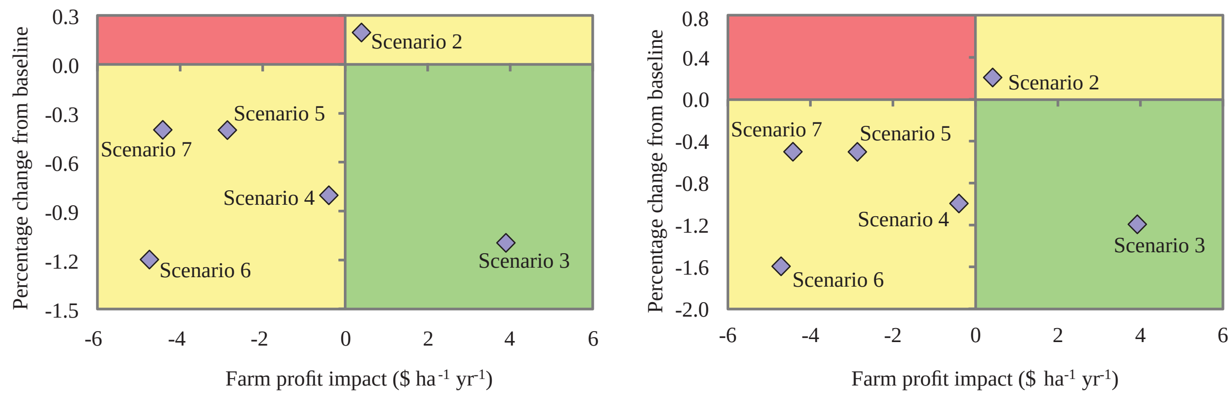
  - ➢ However, individual producer profits may be negative, depending on the size of the intensive feeding operation and the distance the excess manure has to be hauled.
- The remaining scenarios resulted in improved water quality, but at a significant cost to producers.

In Figures 10.7 and 10.8, the BMP scenario environmental and economic results for the RDR study area, IFC, WHC, and LLB are compared. While the scenarios for the RDR study area are not exactly the same as for IFC, WHC, and LLB, the results provide a reasonable comparison of costs and benefits. It is also recognized that animal unit density was more than two times higher in these watersheds than in the RDR study area.

- The IFC Watershed had several cattle backgrounding and finishing operations, while the WHC Sub-watershed 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).

a) Runoff depth

b) Total suspended solids



c) Total nitrogen

d) Total phosphorus

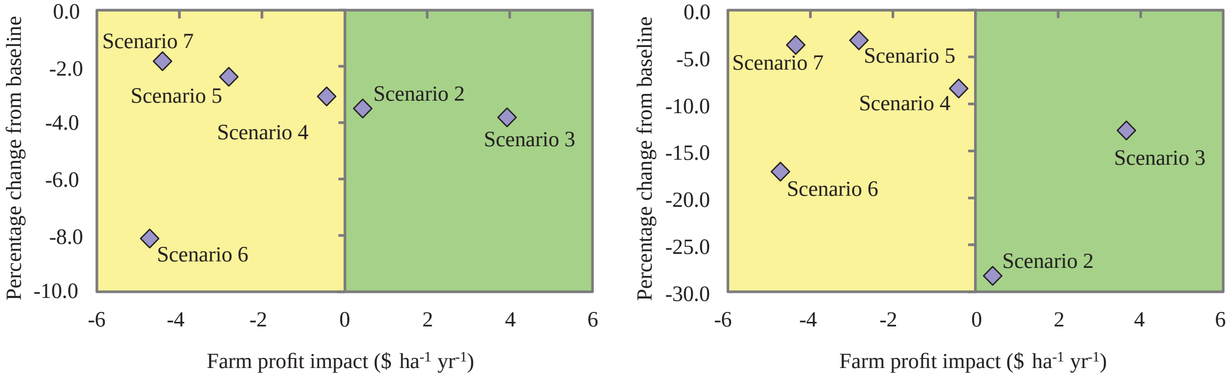


Figure 10.6. The effects of beneficial management practices scenarios on farm profit and (a) runoff depth, (b) total suspended solids (TSS), (c) total nitrogen (TN), and (d) total phosphorus (TP) for the RDR study area. Percent changes in TSS, TN, and TP were in terms of export coefficients.

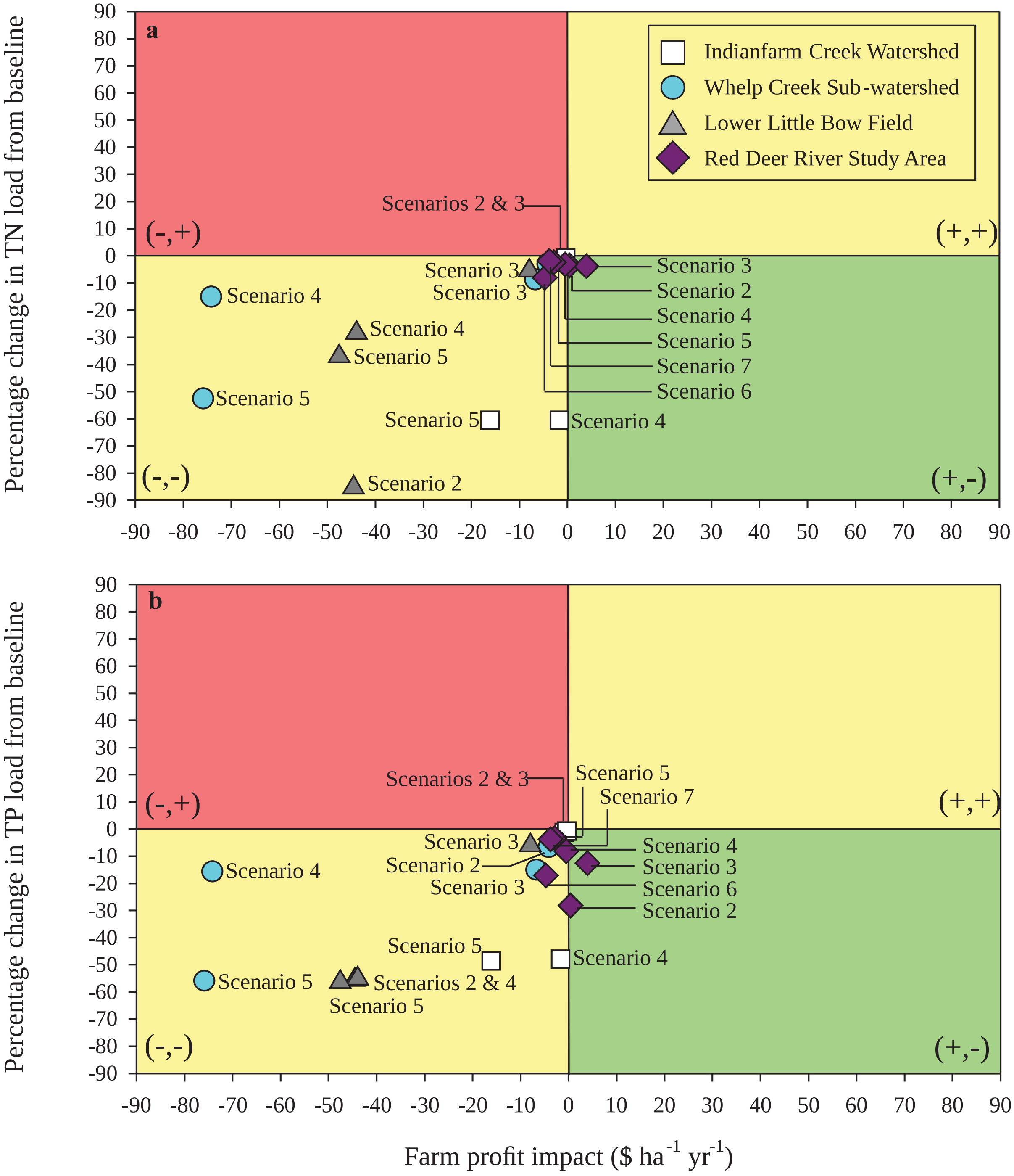


Figure 10.7. Relative change in (a) total nitrogen (TN) and (b) total phosphorus (TP) loads compared to change in farm profit. The minus and plus symbols in parentheses refer to loss (-) or gain (+) in farm profit and degradation (+) or improvement (-) in the environmental indicator.

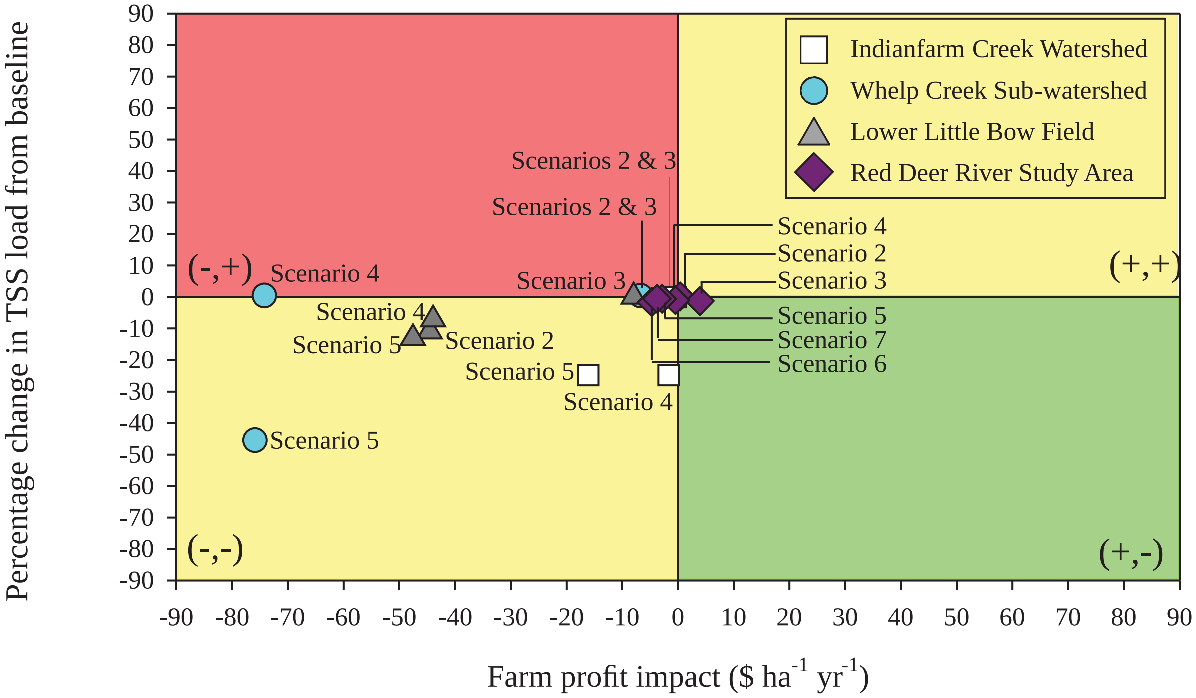


Figure 10.8. Relative change in total suspended solids (TSS) loads compared to change in farm profit. The minus and plus symbols in parentheses refer to loss (-) or gain (+) in farm profit and degradation (+) or improvement (-) in the environmental indicator.

The results for the RDR study area displayed a similar pattern to the IFC, WHC, and LLB study sites despite project differences. In general, the farm economic model estimated a negative return for the majority of farm operations that implemented the proposed BMPs. Scenarios that included agronomic P management had the highest negative returns ranging from $15.50 to $67.50 ha^{-1} yr^{-1} in the IFC, WHC, and LLB watersheds. For the RDR study area, the same BMP generated a positive return of $0.42 ha^{-1} yr^{-1}. 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 scenario in the RDR study area also had a positive economic return of $3.94 ha^{-1} yr^{-1}. In contrast, the riparian setbacks and grassed waterways scenarios resulted in negative economic returns of $4.72 and $2.82, respectively. If all three of these scenarios 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}.

10.4.9 Economic Results at the RDR Study Area Watershed Level

Figure 10.9 shows the baseline economic impact pro-rated to the RDR study area. The study area net returns for all farms totalled about $144 million per year.

The total net returns and the change in total net returns for the RDR study area farms for each BMP scenario are presented in Figure 10.10. The largest gains in net returns are for Scenario 3 as a result of improved forage production and reduced feed costs due to rotational grazing. This BMP is projected to increase total farm net incomes by about $3 million per year. Scenarios 5, 6, and 7 are projected to reduce total farm net returns by $2 to $4 million per year.

10.4.10 Baseline and BMP Scenario Manure Hauling Characteristics

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

Figure 10.11 shows the manure hauling statistics for the RDR study area farms in the baseline scenario. Medium dairy farms require the highest proportion of manure

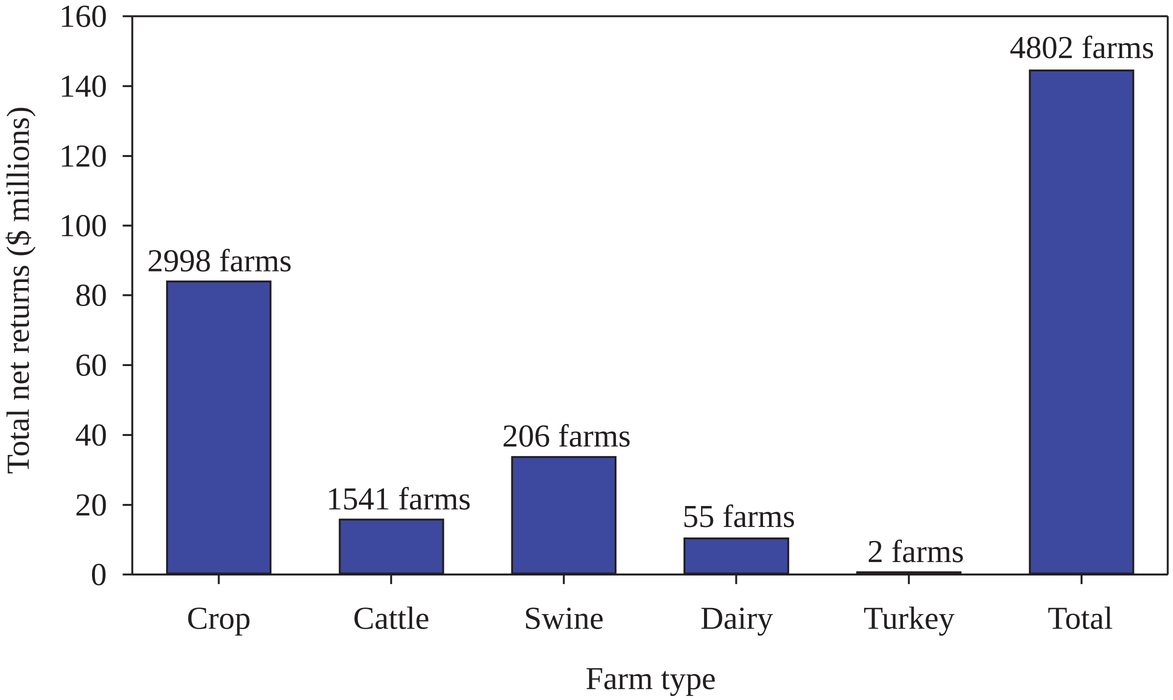


Figure 10.9. Total number of farms represented in the Red Deer River study area and the baseline total net returns by farm type.

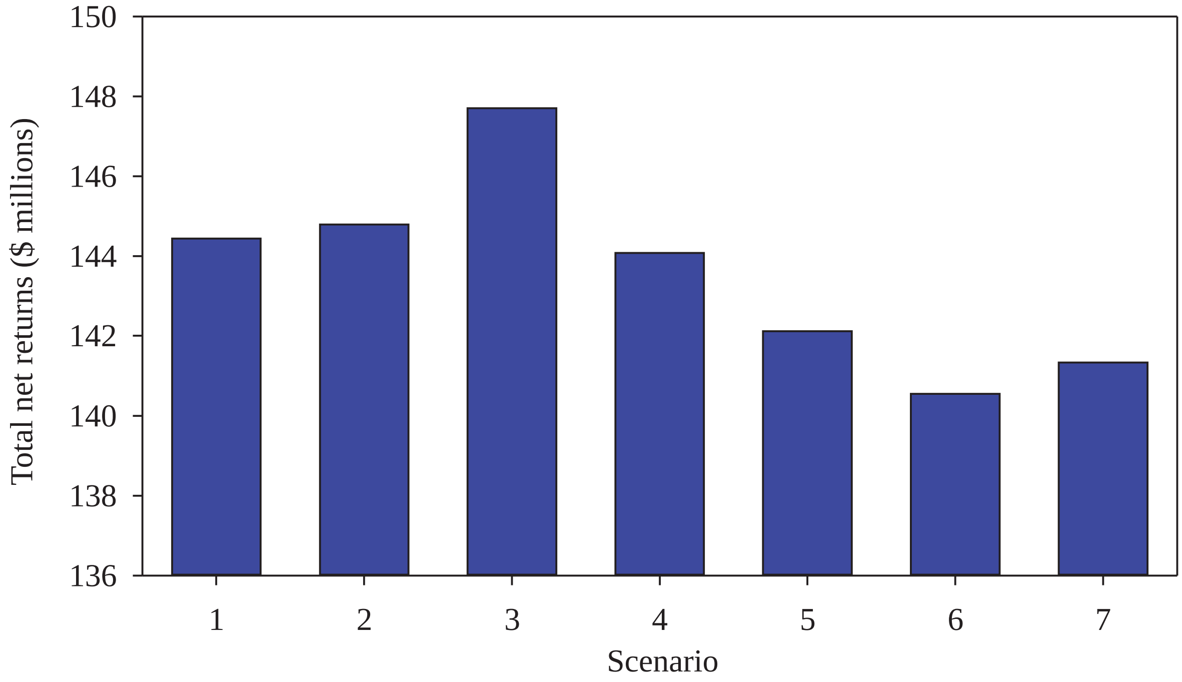


Figure 10.10. Total net returns for the baseline scenario (Scenario 1) and the beneficial management practices scenarios (Scenarios 2 to 7) for farms in the Red Deer River study area.

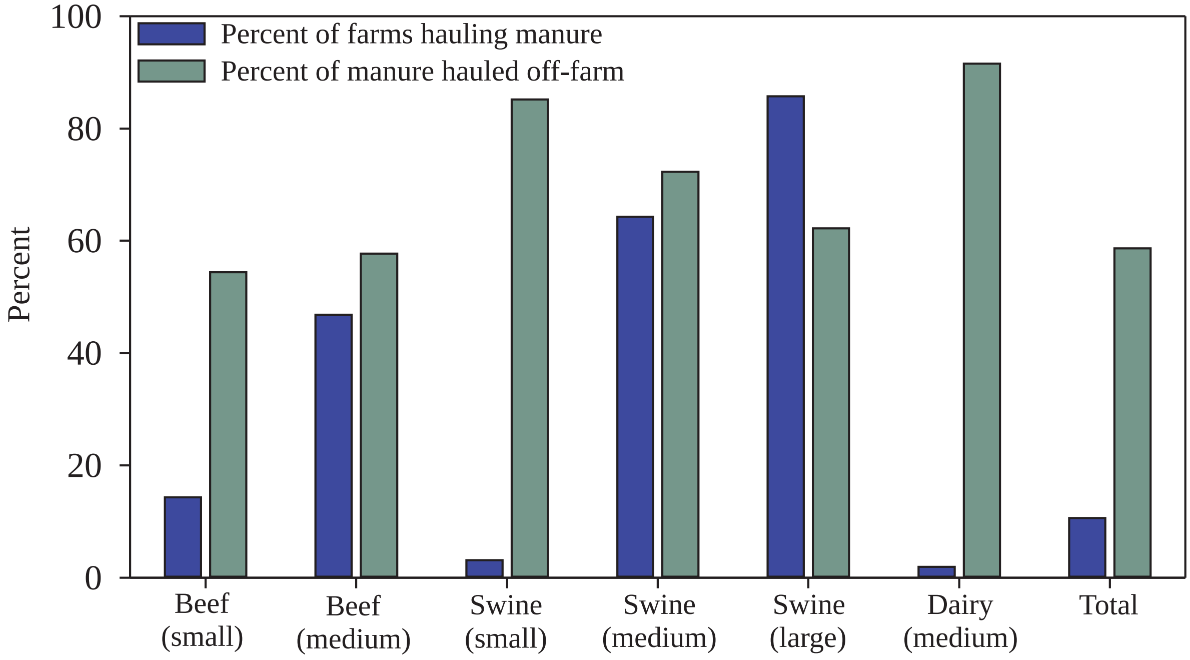


Figure 10.11. Percentage of farms that hauled manure and the proportion of manure hauled off-farm for the baseline scenario.

hauling off-farm, at about 92% of total manure production. Swine farms require high proportions of manure hauling off-farm, ranging from 62 to 85% of total manure production. Small and medium sized cattle farms are required to haul a somewhat smaller proportion, at around 55% of total manure production. Since the number of cattle farms is much higher, they account for the majority of manure hauled.

For the watershed as a whole, the analysis indicates that 511 of the 4802 farms (10.6%) would be required to haul manure off-farm, and the hauling rate was 58.6%. More than half of the study area farms were crop farms, and the small cattle farms were mixed farms with significant cropland.

Table 10.9 shows the impact of the BMP scenarios on the 511 farms in the watershed that hauled manure in the baseline scenario. Therefore, the results are the incremental increase in manure hauling requirements for these farms as a result of the BMP scenarios.

Not surprisingly, the manure management scenario had the largest impact on manure hauling requirements, increasing by 24.6% 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% increase in manure hauling.

Table 10.10 is an assessment of the impact of the six BMP scenarios on the manure handling characteristics of the 4291 farms in the RDR study area that FEM did not require to haul manure off-farm in the baseline scenario. Scenario 2 (manure agronomic P 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%. Scenarios 5, 6, and 7 resulted in slightly more manure hauling off-farm. 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.

Table 10.9. Average increase in the percentage of manure hauling for farms that hauled manure in the baseline scenario.

Scenario[z]	Number of farms hauling manure	% of manure hauled	% 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 10.10. Increase in the number of watershed farms that hauled manure in the beneficial management practices scenarios and average increase in the amount hauled.

Scenario[z]	Number of farms hauling manure	Increase in number of watershed farms	% of manure hauled
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.

10.5 Critical Source Areas

In general, critical source areas (CSAs) are where the landscape conditions are favourable for generating high amounts of surface flow, TSS, and nutrients. Earlier studies indicate that a relatively small portion of a watershed area (i.e., critical source areas) can produce a majority of TSS and nutrient loads (Meals and Budd 1998; Pionke et al. 2000).

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 CSA analyses were completed for seven environmental indicators (TSS, ON, OP, NO_3-N, PO_4-P, TN, and TP). The results were grouped into five risk categories: Very Low, Low, Moderate, High, and Very High.

The risk categories for all of the sub-basins for TN and TP are illustrated in Figure 10.12. Dark green represents sub-basins with Very Low risk ratings while red represents sub-basins with Very High risk ratings.

It was estimated that 12 and 37% of the total RDR study area exported 49% and 74% of TN and TP, respectively. This supports the premise that CSAs contribute a relatively higher proportion of nutrient and sediment loss compared to areas at lower risk within watersheds. Directing BMPs to the higher risk CSAs would likely have a relatively larger positive effect on water quality compared to areas of lower risk. In other studies, White et al. (2009) estimated 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.

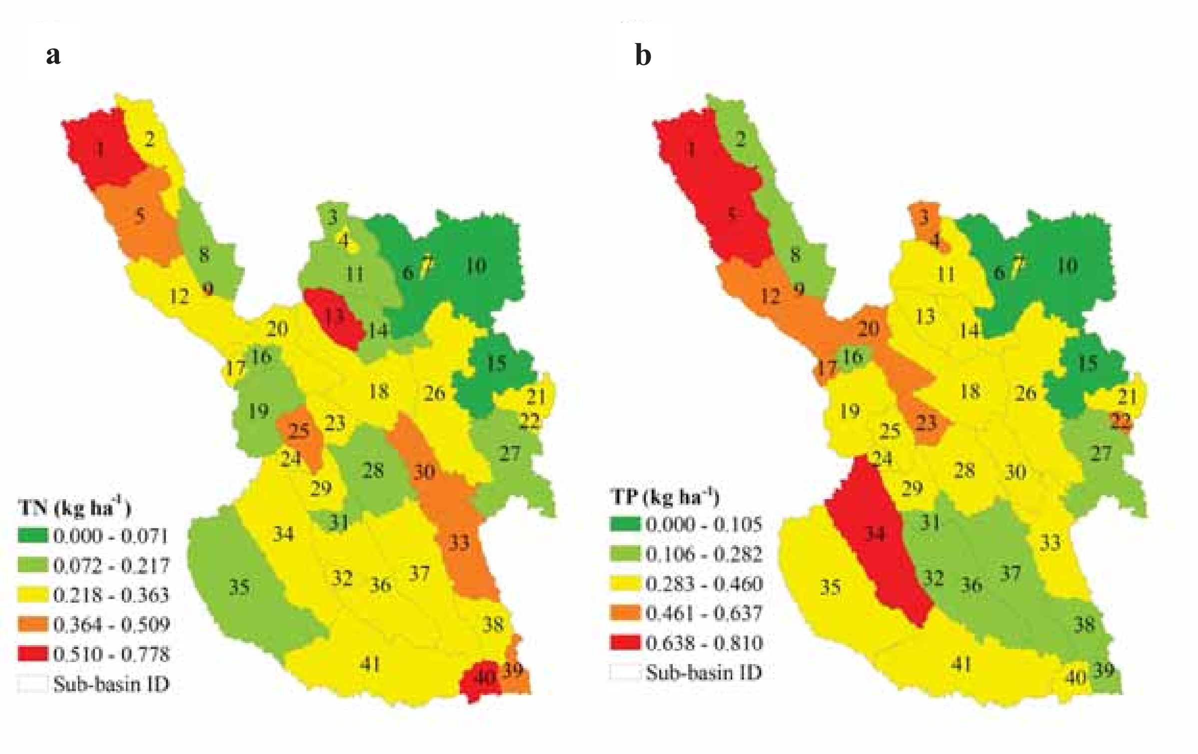


Figure 10.12. Sub-basin scale maps of export coefficients of (a) total nitrogen (TN), and (b) total phosphorus (TP) within the Red Deer River study area.

11 CONCLUSIONS AND RECOMMENDATIONS

11.1 Conclusions

11.1.1 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.

11.1.2 Modelling Study

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 11.1).
- The buffer strips, grassed waterways, and wetland restoration in Scenario 5 showed the greatest environmental improvements in WHC Sub-watershed (Table 11.1), 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 11.1). 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 11.2).

Table 11.1. 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.

    - 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}).

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

Table 11.2. 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

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.

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.

11.2 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 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.

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