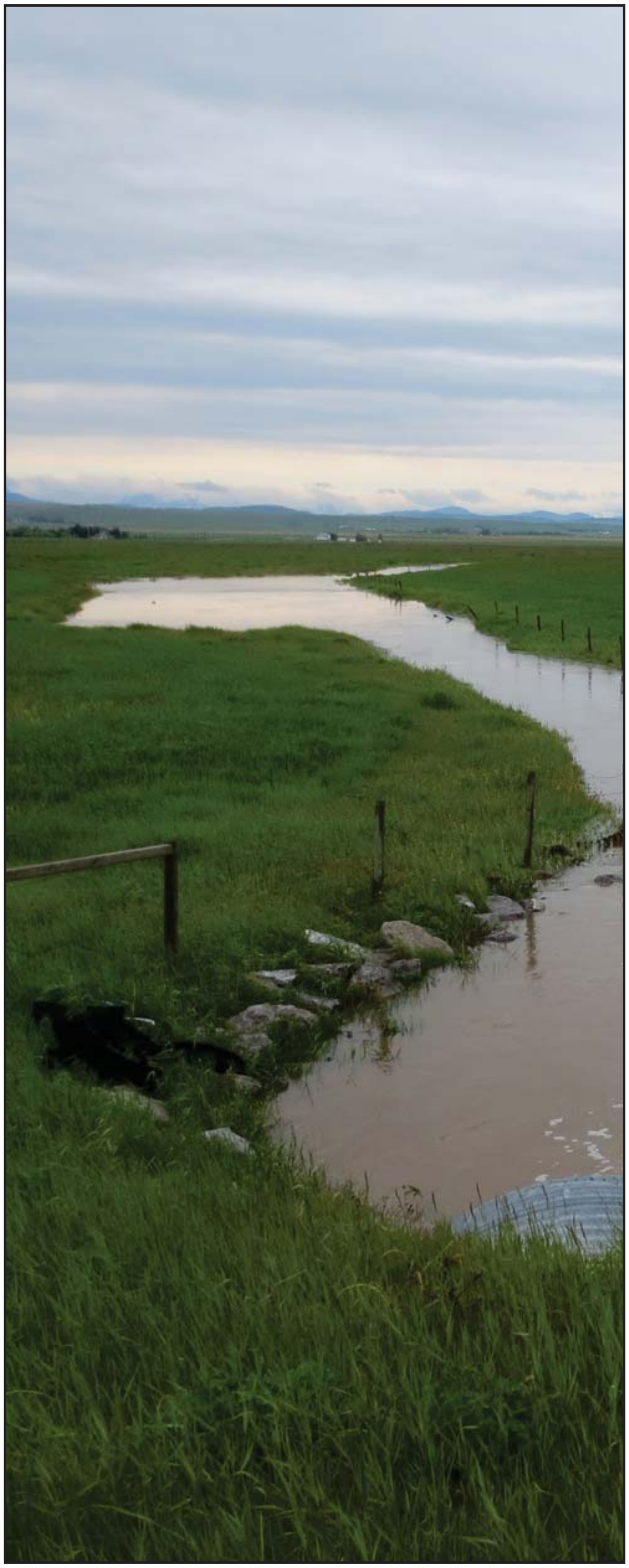
7 FIELD STUDY SYNTHESIS



7.1 Introduction

The objective of this section is to provide an overall synthesis of findings from the watershed field study component of the Nutrient Beneficial Management Practices (BMP) Evaluation Project and situate the findings within a provincial context.

7.2 Project Watershed Comparisons

7.2.1 Watershed Characteristics and Land Use

The Nutrient BMP Evaluation Project (BMP Project) watersheds were similar in that both were small, ephemeral streams that were dominated by agricultural land use. Indianfarm Creek (IFC) generally began flowing in February and Whelp Creek (WHC) in March (Figure 7.1). The average daily flow in both streams was typically less than 1 $m^3 s^{-1}$ (Table 7.1). Both streams were responsive to precipitation events and both were often dry by the end of August. Although the Battersea Drain Field (BDF) was only one field in the Battersea Watershed, the study included sampling in the Battersea Drain, which bisected the field. The Battersea Watershed was similar to the IFC and WHC watersheds as it too was dominated by agricultural land use and the Battersea Drain typically had less than 1 $m^3 s^{-1}$ of flow. The Lower Little Bow Field (LLB) was not included in these watershed comparisons because the Lower Little Bow River was not sampled during this study.

While there were similarities between the study watersheds, there were far more differences. 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 in two natural regions (Table 7.1) and average annual precipitation varied. Indianfarm Creek tended to flow about two to three months longer and have higher daily flows than WHC, and hence, IFC tended to generate

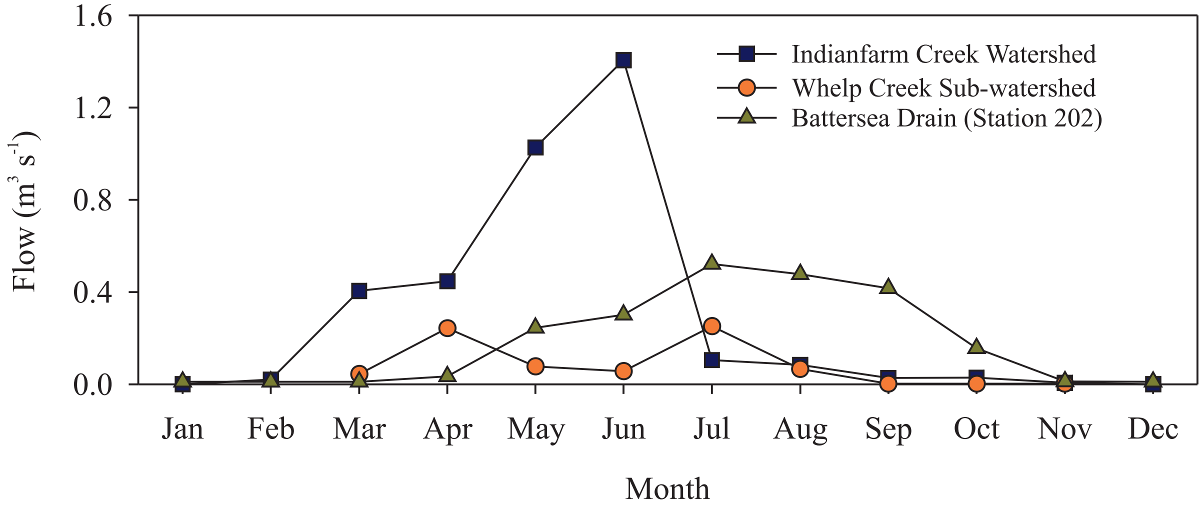


Figure 7.1. Average monthly flows from 2007 to 2012 in the Nutrient Beneficial Management Practices Evaluation Project watersheds. Flows were monitored at the outlets of Indianfarm Watershed and Whelp Creek Sub-watershed and about mid-way through the Battersea Drain (Station 202). Flow data were not collected for Whelp Creek in 2007.

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. Also, the topographic relief was greater in IFC compared to WHC. Subsequently, because of these precipitation and topographic differences, flow in IFC was flashy with quick ascent and descent of relatively deep flows; whereas, WHC was generally shallow and slow flowing. The hydrology of the Battersea Drain was dependent on irrigation management within the Lethbridge Northern Irrigation District. The flow in the drain tended to be steady during the crop growing season, although fields occasionally contributed small amounts of runoff to the drain during irrigation, rainfall, or snowmelt.

While mixed farming occurred within all of the watersheds, the farm practises varied. Within IFC Watershed, much of the crop cover was perennial (Table 7.1), in part, because of the high winds that made soil susceptible to erosion. Within the IFC Watershed, while most of the livestock were in confined feeding operations (CFOs), livestock were also extensively found in cow-calf operations. The livestock in the IFC Watershed were often concentrated or fenced into riparian pastures. In contrast, farming in WHC and the Battersea areas were dominated by CFOs with very little grazing. The manure that was produced in the CFOs within the WHC Sub-watershed was applied to surrounding cropland, which were most often annual cereals. Practices in the Battersea Watershed were more similar to WHC than IFC, and the Battersea area was unique in that it was dominated by irrigated cropland.

Table 7.1. Characteristics of Nutrient Beneficial Management Practices Evaluation Project watersheds and field sites. The Battersea Drain Field (BDF) site was within the Battersea Drain Watershed. The Lower Little Bow (LLB) site was within the Lower Little Bow Watershed (not shown), which has many similar characteristics to the Battersea Watershed.

Characteristic	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 growing season flows (late April to late October) 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 within the Battersea Drain area.

7.2.2 Water Quality

Given the differences between the study watersheds, the drivers and patterns of water quality were also different. The easiest observed water quality difference between IFC and the other study watersheds was the amount of particulates (Figure 7.2c). The total suspended solids (TSS) concentrations in IFC were about 3- to 10-fold higher than BDF and WHC. In the IFC Watershed, most water quality parameters were correlated with runoff and flow. Landowners in IFC Watershed had commented on the erosive nature of the creek during large rainfall events. Similarly, the proportion of particulate phosphorus (PP) in IFC tended to be higher than PP concentration in BDF and WHC. Water quality in WHC was not correlated with flow and WHC typically had higher nutrient concentrations than IFC (Figure 7.2). Whelp Creek tended to have a high proportion of organic nitrogen (ON) than IFC and BDF, and this may be related to the higher proportion of runoff that occurred as snowmelt (Casson et al. 2008).

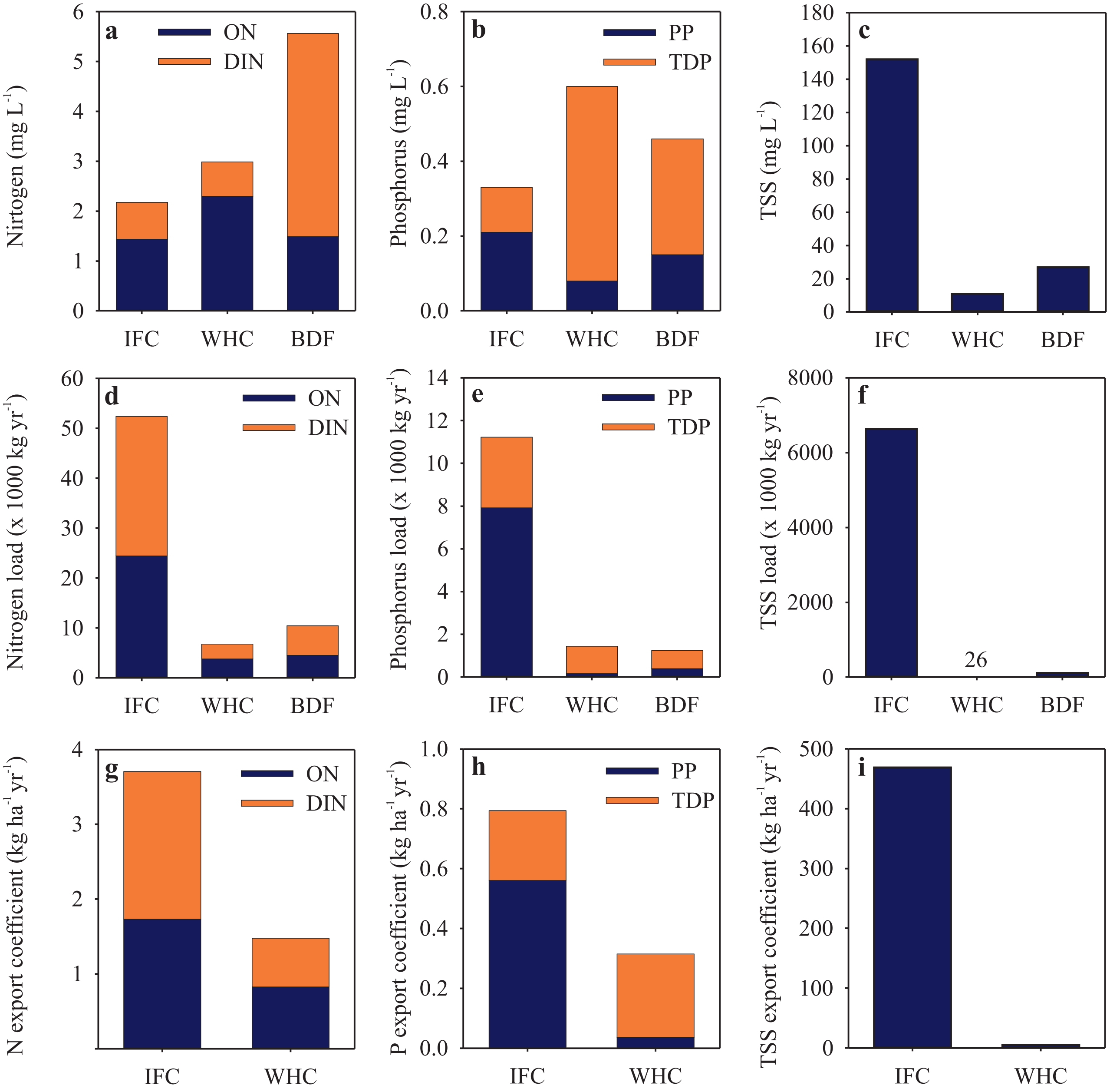


Figure 7.2. Average (a, b, c) 6-yr (IFC and BDF) or 5-yr (WHC) concentrations, (d, e, f) annual loads, and (g, h, i) annual export coefficients of organic nitrogen (ON), dissolved inorganic nitrogen (DIN), particulate phosphorus (PP), total dissolved phosphorus (TDP), and total suspended solids (TSS) at the outlets of Indianfarm Creek (IFC) Watershed and Whelp Creek (WHC) Sub-watershed. The Battersea Drain was monitored at Battersea Drain Field (BDF) Station 202, which was about mid-way in the water course. Export coefficients cannot be calculated for irrigation watersheds given the artificial hydrology introduced by irrigation canals and pipelines.

Despite the trend of lower nutrient concentrations in IFC than BDF and WHC, the load and export coefficients from IFC were higher than the other study watersheds (Figure 7.2). Differences in export coefficients have previously been observed throughout agricultural watersheds in Alberta. The Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds study (Lorenz et al. 2008) found that exports varied among natural regions due to differences in precipitation and subsequently runoff and flow. Previous data showed that regardless of agricultural intensity, streams with high flows and low concentrations could contribute more loads than streams with low flows, but high concentrations (Anderson et al. 1998). Similarly, in the BMP Project, flow was the primary driver for the observed load and export coefficient differences at the watershed outlets. The average annual flow in WHC was about three and six times lower than BDF and IFC, respectively.

The scale of water quality measurement in a stream is important. Generally, the smaller the scale (or the smaller Strahler stream order), the higher the concentration of nutrients expected. The overall trends in the BMP Project watersheds showed that nutrient water quality concentrations tended to be highest at the edge-of-field > tributaries > outlet (Figure 7.3). For example, the total nitrogen (TN) concentrations in the IFC Watershed were 2- to 10-fold higher at the edge-of-field than at the mainstem sites. Similarly, total phosphorus (TP) concentrations were 2- to 6-fold higher (Appendices 6 and 7). Additionally, the proportion of the total nutrients in the dissolved form tended to increase as the scale of monitoring decreased (Figure 7.3; Appendices 6 and 7). For example, the amount of total dissolved phosphorus (TDP) in proportion to TP was highest at the edge-of-field > tributaries > outlet.

Sediments and bacteria do not always behave the same as nutrients when examining the relationship between concentration and the scale of monitoring. In WHC, TSS tended to be highest at edge-of-field, then the tributaries, and lastly the outlet. In IFC, TSS was highest at the outlet followed by the tributaries and then edge-of-field (Figure 7.4). The sediments in IFC likely reflected that the majority of erosion occurred within the mainstem and tributaries rather than at the edge-of-field. 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 7.4; Appendices 6 and 7).

7.2.3 Soil Nutrients and Water Quality

A total of 22 BMP and reference sites were established during the study. Of these sites, detailed, nutrient status (extractable N and P) of the surface soil (0 to 15 cm) was determined for 15 sites. In IFC Watershed, the sites included North Manure Field (NMF), Pasture site (PST), South Manure Field (SMF), Dairy Manure Field (DMF), and Reference site (REF). In WHC Sub-watershed, the sites included West Field (WFD), North Field (NFD), East Field (EFD), South Field (SFD), North Pasture (NPS), South Pasture (SPS), Reference 1 (REF1), and Reference 2 (REF2). The remaining two sites were BDF and LLB. For the purpose of presenting soil nutrient data, the SMF was divided into two fields (SMF-south and SMF-north), the PST site was separated into the corral area (PST-corral) and the remainder of the pasture (PST), and the NFD was separated into four fields (NFD-SW, NFD-NW, NFD-NE, and NFD-SE). Further details about these sites and the other BMP sites are presented in Sub-section 7.3.

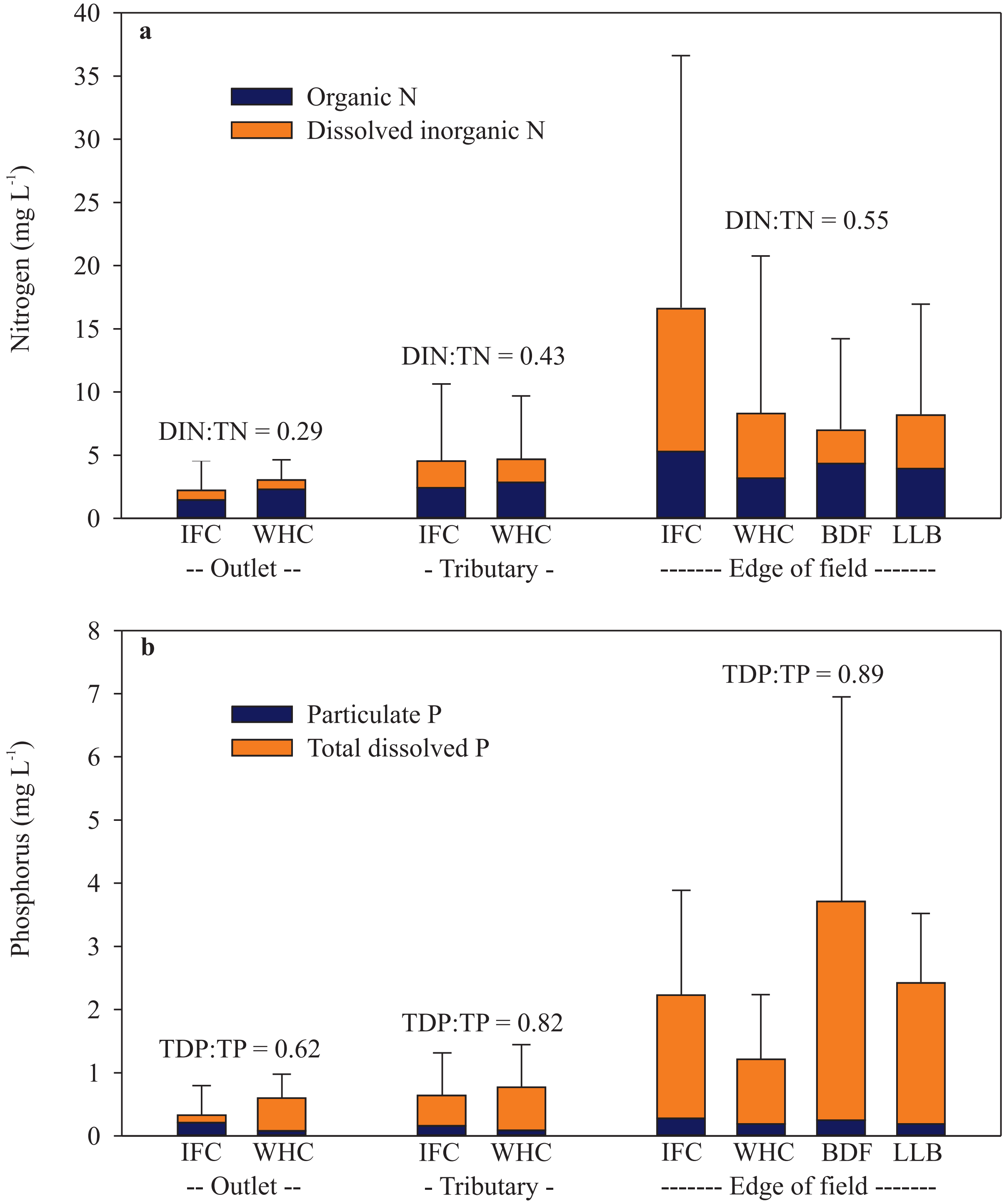


Figure 7.3. Average concentrations of (a) nitrogen (N) and (b) phosphorus (P) in water at the outlets and main tributaries of Indianfarm Creek (IFC) Watershed and Whelp Creek (WHC) Sub-watershed and in runoff water at edge-of-field in IFC Watershed, WHC Sub-watershed, Battersea Drain Field (BDF), and Lower Little Bow Field (LLB). The t-bars are standard deviations for total N (organic plus dissolved inorganic) and total P (particulate plus dissolved).

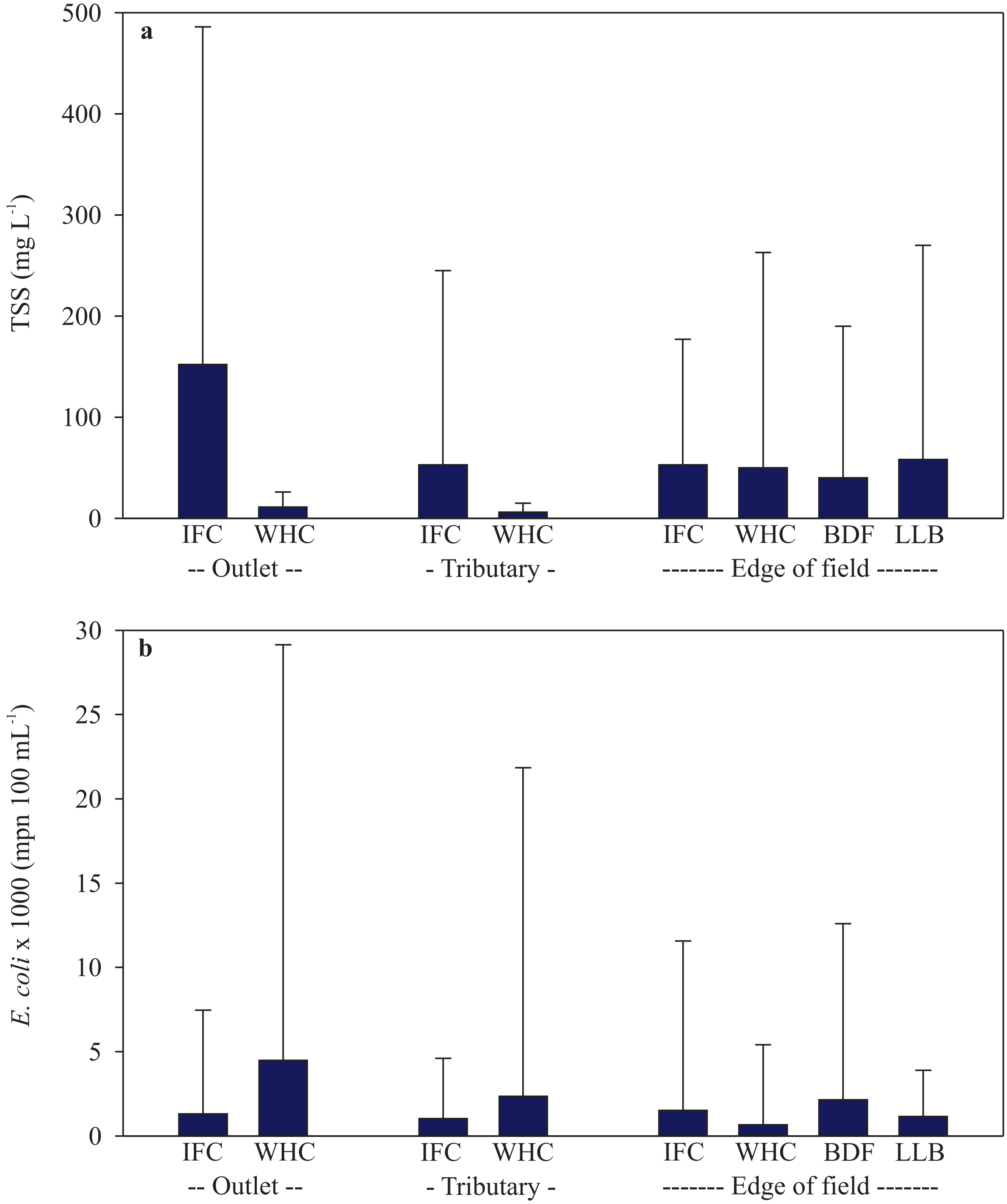


Figure 7.4. Average concentrations of (a) total suspended solids (TSS) and (b) *Escherichia coli* (*E. coli*) in water at the outlets and main tributaries of Indianfarm Creek (IFC) Watershed and Whelp Creek (WHC) Sub-watershed and in runoff water at edge-of-field in IFC Watershed, WHC Sub-watershed, Battersea Drain Field (BDF), and Lower Little Bow Field (LLB). The t-bars are standard deviations.

Agronomic soil samples were collected each spring and fall from the 0- to 15-cm soil layer at all of the annual and perennial crop fields (Sub-section 2.9.2). Similar types of soil samples were also collected either once or twice at the pasture sites. The purpose of the agronomic samples was to assess the nutrient status of surface soil prior to main runoff events, i.e., fall samples for the following snowmelt, and spring samples for runoff generated by rainfall or irrigation. 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. The distinction between manured and heavily manured fields was based on average STP concentration in the 0- to 15-cm soil layer, whereby, it was assumed that the more manure P that was applied, the higher the STP concentration. Factors that influence the accumulation of STP include application frequency, application rate, and manure quality (i.e., nutrient concentrations and ratios). In addition to the cultivated field sites, pasture sites were placed in a fourth category.

As manure intensity increased, the average concentration of nitrate nitrogen (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 moderately manured sites, and 36 mg kg^{-1} for heavily manured sites (Figure 7.5a). The average concentration was lowest for the pasture sites at about 7 mg kg^{-1}. These findings are similar to those found by 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 ungrazed grassland site. The concentration of NO_3-N at the EFD site was much less than the other moderately manured fields. This site had a history of manure application, but early in the study, the site was converted from annual crop to alfalfa production and manure was either not applied (2008 and 2009) or only applied to a portion of the field (2007, 2010, and 2011) (Sub-section 4.8). Therefore during the study, the NO_3-N concentration was reduced by the alfalfa crop.

Unlike for NO_3-N, the concentration of ammonium nitrogen (NH_4-N) was relatively consistent, with average concentrations that ranged from 6 to 9 mg kg^{-1} among the four categories (Figure 7.5b). This was not surprising as NH_4 tends not to accumulate in soil, but rather is converted to NO_3 through nitrification. Therefore, the status of NH_4-N concentration in soil did not reflect management practices or nutrient sources. In fact, one of the heavily manured sites (LLB) had the lowest average concentration of NH_4-N in the 0- to 15-cm soil layer.

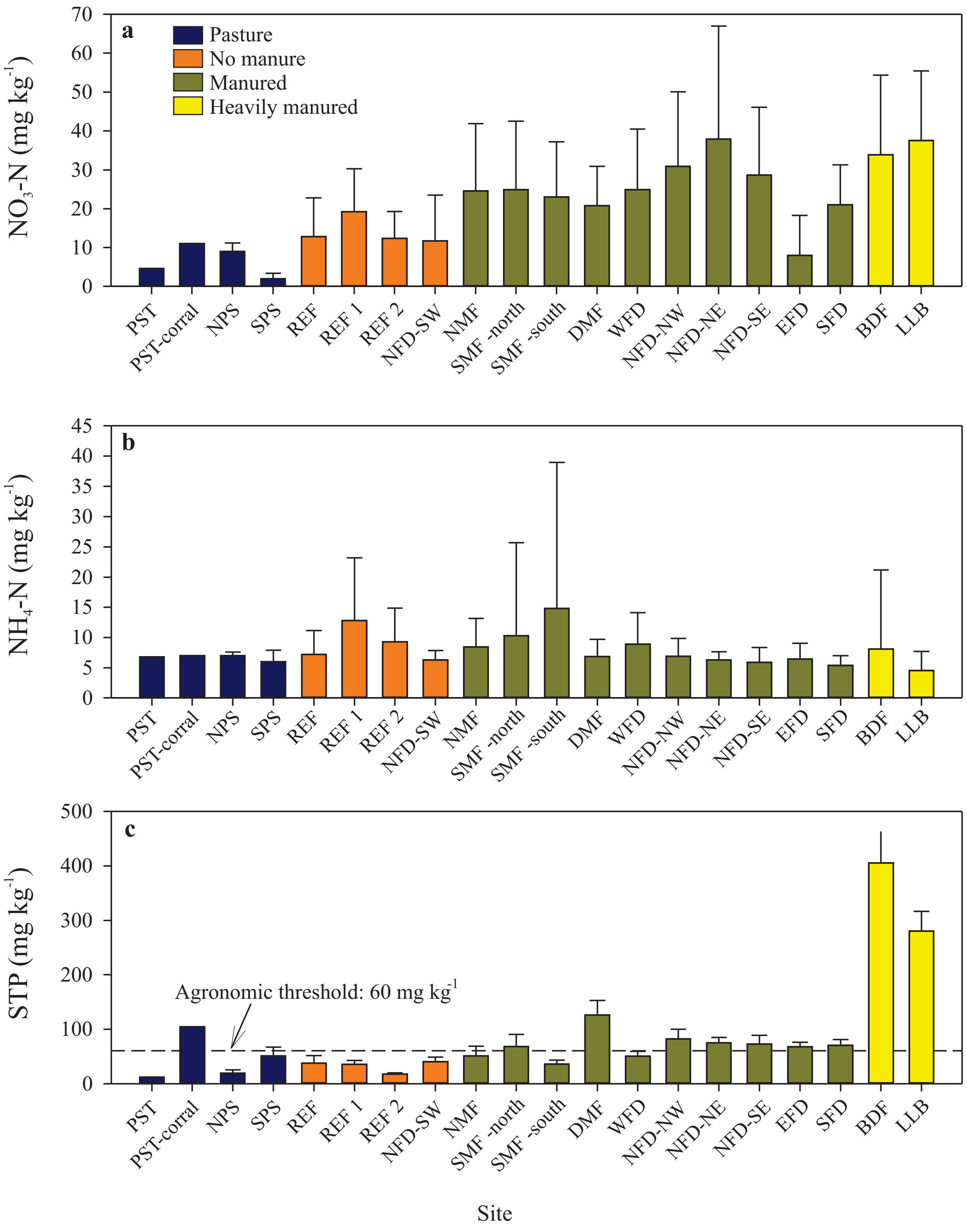


Figure 7.5. Average concentration of (a) nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and (c) soil-test phosphorus (STP) in the surface soil (0 to 15 cm) at the beneficial management practices sites from 2007 to 2012. Averages were determined from values obtained for each sampling event. For most sites, n = 10 to 12, except for SMF-south (n = 6), NPS (n = 3), SPS (n = 2), PST (n = 1), and PST-corral (n = 1). The t-bars are standard deviations.

Similar to no-manure and manured site soil-test phosphorus (STP) findings from Little et al. (2007), there was a clear distinction of STP concentration differences among the categories in the current study. The average concentration of STP was 33 mg kg^{-1} for the no-manure sites (Figure 7.5c). The average concentration was more than doubled at 70 mg kg^{-1} for manured sites. For the two heavily manured sites, the average concentration of STP was nearly five-fold greater compared to the manured soils. None of the no-manure sites were above the agronomic threshold of 60 mg kg^{-1} (Howard 2006); whereas, this was not the case for most of the manured sites. The average concentration for the pasture sites was intermediate between the no-manure and manured sites.

The results clearly show that when manure is introduced into a cropping system, the concentration of STP will increase. Fields with a slight accumulation of P can be reduced in STP concentration within a few years, but fields with a long-term accumulation of P will likely take decades to reduce in STP. This was demonstrated by the four fields at the NFD site in the WHC Sub-watershed. One of the fields (NFD-SW) was in alfalfa production and received no manure or P fertilizer during most of the study. Compared to the other three fields (NFD-NW, -NE, and -SE), STP concentration decreased to less than the agronomic threshold in the NFD-SW. In contrast are the BDF and LLB sites, which both have a long history of heavy application of beef manure and soils were well in excess of crop nutrient requirements. Because of the high STP concentration at these two sites, the BMP plans included no application of any form of P, including manure. At both sites, even though manure was not applied for 3 yr during the post-BMP period, the STP concentration in the surface soil did not significantly change. This demonstrated that the residual accumulation of organic P from manure will maintain high STP concentration for several years after manure application is stopped.

If manure or livestock are confined to a small area, nutrients can quickly accumulate in soil. Among the manured sites, the DMF site had the highest STP concentration (Figure 7.5c). At this site, dairy manure was applied at very high rates, but to only a few hectares in a given year. With time, this practice resulted in P accumulation to more than 120 mg kg^{-1} on average. The corral area (PST-corral) had a relatively high STP concentration, at slightly more than 100 mg kg^{-1}, compared to other pasture sites and even compared to many of the cropped sites (Figure 7.5c). The corral area was within the PST site and was particularly affected by congregating of cattle, which resulted in high densities of fecal pats in this area compared to the rest of the pasture (Sub-section 3.7). This resulted in higher STP concentration, relative to the whole PST site, which had low STP concentration of only 12 mg kg^{-1}. It is also interesting that the corral area had the highest average concentration of NO_3-N compared to the other pasture sites (Figure 7.5a).

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 7.5 were monitored for edge-of-field runoff water quality. These sites included PST-corral, SPS, REF, REF1, REF2, NFD-SW, NMF, DMF, WFD, EFD, SFD, BDF, and LLB. Results from the 13 sites showed no relationship between soil extractable NO_3-N and TN in runoff water (Figure 7.6a). This was also true for NO_3-N concentration in runoff water when compared to NO_3-N concentration in soil (data not shown). This supports other work in Alberta by Casson et al. (2008) who concluded that soil extractable NO_3-N is a weak predictor for the loss of TN and NO_3-N in runoff water at the edge-of-field.

In contrast, the concentration of TP in runoff water increased as the concentration of STP increased (Figure 7.6b). A similar relationship was also observed for TDP in runoff (data not shown). A hyperbolic curve was fitted to the data. The curve-linear relationship reported here is in contrast to the linear relationship reported by Little et al. (2007) for eight Alberta watersheds, which were monitored for 3 yr. In the current study, the four sites with the highest average STP concentration also had the highest average TP concentration in runoff water. However, the TP concentration in runoff at the LLB site was similar to the PST-corral and DMF sites, even though the former site had much higher STP concentration than the latter two sites. Other factors, in addition to STP, likely affect the release of P into runoff water. Removing the BDF and LLB sites from the dataset shows that the general trend of increased TP in runoff water as STP concentration increased was still evident for STP concentrations less than 125 mg kg^{-1} (Figure 7.6c). Often for low STP values or for a narrow range of STP values (e.g., 50 mg kg^{-1}), the relationship between STP and P in runoff is weaker compared to wider ranges of STP. The relationship was still curve-linear (Figure 7.6c). However, several sites with similar average STP concentrations (i.e., 40 to 50 mg kg^{-1}) produced a wide range of TP concentrations in runoff water. The REF site in particular had less than 40 mg kg^{-1} STP, but a relatively high TP concentration in edge-of field runoff. Other factors need to be taken into consideration. At the REF site, fall grazing of cattle was practiced, and it was believed that the presence of cattle in the field drainage channel may have increased nutrient loss in runoff water.

The results from the current study suggest that elevated STP concentration, even to a moderately high value (80 to 120 mg kg^{-1}), will likely increase the risk of P loss in runoff water. The key, particularly for manure nutrient management, is to monitor STP closely, and to avoid the accumulation of soil P. For soils already high in STP, a long-term nutrient management plan is required to reduce STP concentration to levels that pose less risk. Previous work in Alberta suggested that a maximum STP limit for Alberta should not exceed 200 mg kg^{-1} (Paterson et al. 2006). However, for agricultural cropping systems, reducing STP to near agronomic levels or less than agronomic levels will reduce the risk of P loss from the source (Figure 7.6b,c).

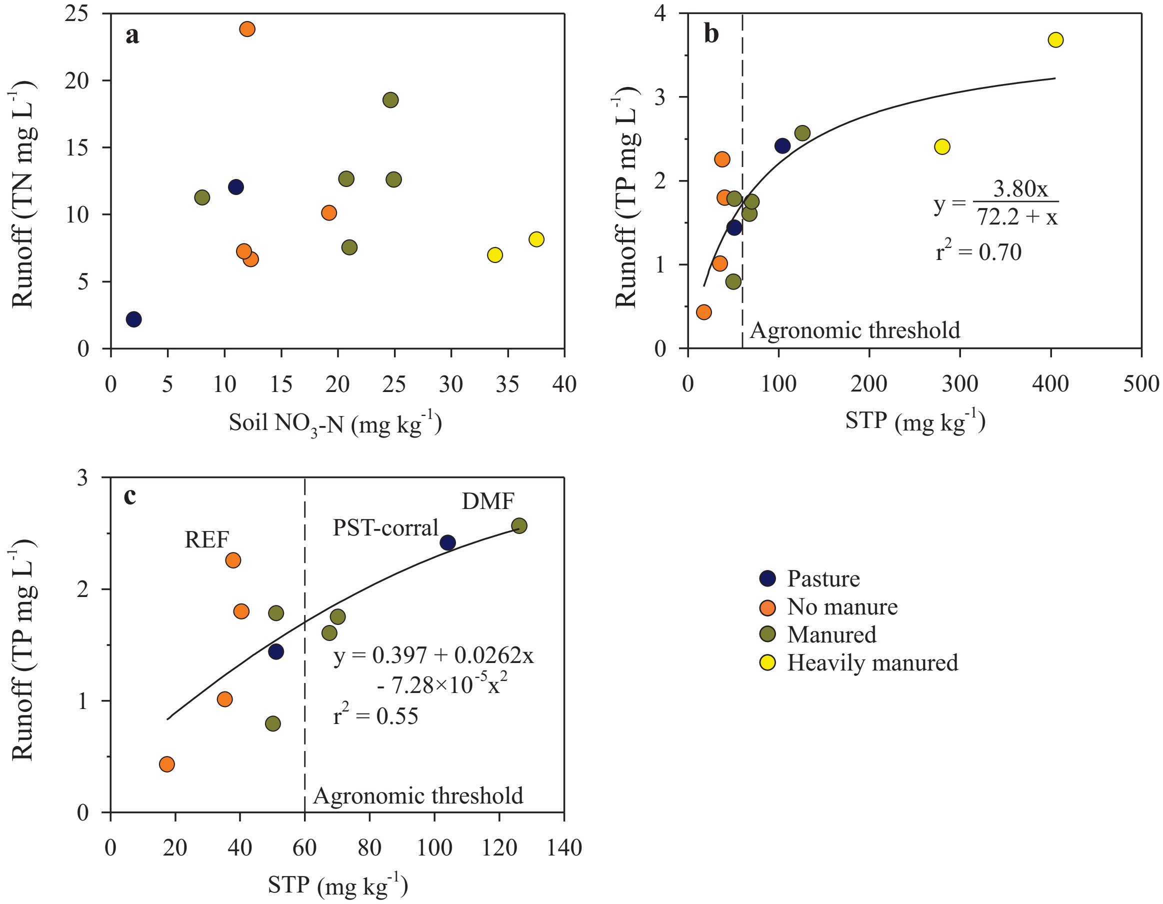


Figure 7.6. The relationships between (a) soil extractable nitrate nitrogen (NO_3-N) and total nitrogen (TN) in edge-of-field runoff water and (b, c) between soil-test phosphorus (STP) and total phosphorus (TP) in edge-of-field runoff water.

7.3 BMP Assessment

Of the 22 sites established for the project (Table 7.2), plans were developed to implement BMPs at 20 of the sites. However, successful BMP implementation occurred at only 16 sites. The efficacy of the BMPs on water quality was assessed at 11 sites (Table 7.2) and each of the sites was classified based on water quality concerns related to on-farm livestock, crop nutrients, and/or surface-water management (Tables 7.3 and 7.4). The efficacy of BMPs was assessed at three additional sites, which did not have water quality data, using riparian and rangeland assessments (Table 7.2).

Table 7.2. A summary of project study sites, sites for which BMP plans were developed, sites that were successfully implemented with BMPs, and sites where BMPs were able to be evaluated using environmental indicators.

				BMP evaluation carried out					
	Site[z]	BMP plan developed	BMP plan successfully implemented	Water quality	Water quantity	Soil nutrients	Riparian	Rangeland	Photo points
Indianfarm Creek Watershed	IMP	✓	✓	✓			✓		
	NMF	✓	✓	✓					
	PST	✓	✓	✓			✓	✓[y]	
	WIN	✓	✓	✓			✓		
	SMF[x]	✓							
	DMF[w]	✓							
	REF[v]	✓							
	FLT[u]	✓	✓					✓[t]	✓
	DUG	✓	✓				✓		✓
	OSW	✓	✓				✓		✓
	FEN[s]	✓	✓						
	CAT	✓	✓						
Whelp Creek Sub-watershed	WFD	✓	✓	✓					
	NFD	✓	✓	✓					
	EFD[r]	✓							
	SFD	✓	✓	✓					
	NPS	✓	✓	✓				✓[q]	✓
	SPS	✓	✓	✓				✓[q]	
	REF1[p]								
	REF2[p]								
Irrigated field sites	BDF	✓	✓	✓	✓	✓			
	LLB	✓	✓	✓	✓	✓			
Number of sites	22	20	16	11	2	2	5	4	3

[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] Rangeland survey and rangeland production.

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

[w] The BMP plan was only implemented for 1 yr due to wet weather and field access issues.

[v] 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 1 yr and then the BMP could not be maintained because of a crop failure, a change in crop management, and flooding of the drainage channel.

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

[t] Rangeland survey.

[s] The BMP could not be evaluated because of cold weather, equipment failure, and failure of the erosion control.

[r] 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.

[q] Rangeland production.

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

Table 7.3. A description of issues and the beneficial management practice (BMP) plans for the BMP sites in the Indianfarm Creek Watershed.

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.

Table 7.4. A description of issues and the beneficial management practice (BMP) plans for the BMP sites in the Whelp Creek Sub-watershed and at the two irrigated field sites (BDF and LLB).

Site[z]	Type[y]	Issues	BMP plan
		Whelp Creek Sub-watershed	
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
		Irrigated field sites	
BDF	N,S	• Very high level of soil P from manure application • Field drains into an irrigation canal • Irrigation generated runoff	• Stop manure application and nutrient management plan • Pivot modification and irrigation management to control runoff from irrigation
LLB	N,S	• Very high level of soil P from manure application • Field drains into a coulee channel • Irrigation generated runoff	• Stop manure application and nutrient management plan • Pivot modification and irrigation management to control runoff from irrigation • Grass cover in drainage channel

[z] NFD = North Field, WFD = West Field, EFD = East Field, SFD = South Field, NPS = North Pasture, SPS = South Pasture, BDF = Battersea Drain Field, 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; S = surface-water management BMPs involved timing of irrigation and pivot modification to reduce irrigation runoff from sensitive areas.

On-farm management concerns for each site were addressed by implementing several BMPs that were developed with the cooperating producers and were site specific. Hence, the study design focused on evaluating the efficacy of BMPs to address on-farm management concerns using multiple BMPs (Tables 7.3 and 7.4), rather than assessing individual BMPs. This approach focused more broadly on water quality issues of concern, rather than individual and site-specific BMPs.

During the study, there were examples where BMP plans were not implemented, partially implemented, or implementation was delayed. These included the SMF, DMF, REF, and CAT sites in IFC Watershed; the NFD, SFD, EFD sites in WHC Sub-watershed; and the BDF and LLB sites. Contributing factors included poor weather and field access (SMF, DMF), untimely access to manure-spreading equipment (NFD, SFD), change in crop management (EFD), producers not willing to implement or maintain a portion of the BMP plans (NFD, CAT, BDF), and technical difficulties with equipment (BDF and LLB). At the NFD site, the producer was not willing to switch from fall to spring manure application, and at the BDF site, manure application started again after only three years of no manure application. The BMP plan for the CAT site to manage surface water included three components, but because of cost and time commitments, the producer decided to implement only one of the components. These are a few examples of challenges in the implementation of BMPs in the current study. Others have studied and reviewed the many barriers that may be associated with BMP adoption, including Brant (2003) and Alberta Research Council (2006).

7.3.1 BMP Improvement on Water Quality

Eight of the 11 BMP sites were effective in improving water quality (Table 7.5). The location or scale of monitoring was important in assessing the BMPs. It was expected that changes would be best detected at the edge-of-field as the water quality concentrations tended to be higher at the edge-of-field compared to instream (Sub-section 7.2.2). Also, at field scale, BMPs have a more direct effect on edge-of-field runoff, compared to the instream scale, which has a larger volume of water flowing from a larger area than field scale. Eight of the BMP sites were monitored either at the edge-of-field (five sites) or instream (three sites). Three of the BMP sites (PST, NFD, and BDF) were monitored at the edge-of-field and instream, and two of these sites had conflicting results as statistically significant water quality improvements was measured at the edge-of-field but not instream (Table 7.5). Where monitoring occurred at two scales, the BMPs were deemed effective at improving water quality based on the edge-of-field results.

Of the six BMP sites that involved cattle management, four were effective at improving water quality (Table 7.5). Three of the four effective BMP sites (NMF, WIN, and PST) were in the IFC Watershed while one site (NPS) was in the WHC Sub-watershed. Each of the effective BMPs significantly reduced one to three of the main water quality parameters. Three of the sites had a significant reduction in TN and *E. coli*, two sites had a reduction in TP and one site had reduced TSS. The PST-corral BMP was effective at significantly reducing TN, TP, and *E. coli* when monitored at the edge-of-field, and while not statistically significant, there were some trends for improvement in IFC downstream of the PST site.

Table 7.5. Summary of water quality changes in the pre- and post-BMP period during active runoff events (snowmelt, rainfall, and irrigation) of the six-year study. 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.

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

Change in the post-BMP period compared to the pre-BMP period:

- * (blue) Significant (P <0.1) improvement
- (blue) Non-significant improvement
- * (pink) Significant (P <0.1) degradation
- (pink) Non-significant degradation
- (white) Little or no change

[z] Difference between instream Stations 11 (downstream) and 12 (upstream).
[y] Difference between instream Stations 302 (downstream) and 301 (upstream).
[x] Difference between instream Stations 9 (downstream) and 10 (upstream). Samples were only compared when flow was connective between the stations.
[w] Difference between instream Stations 5 (downstream) and 8 (upstream), which captured runoff from the corral area.
[v] Both stations are edge-of-field but not connective; Station 310 was furthest downstream, while Station 311 was about mid-field.
[u] The only BMP that was effectively implemented was for erosion control so the reduced TSS concentration was considered positive.
[t] The 2009 water quality data were not included in the statistical analysis.
[s] 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.
[r] Four edge-of-field stations captured runoff from the same field, which was a quarter section in size.
[q] Difference between instream Stations 202 (downstream) and 201 (upstream).
[p] High = high-flow period from late-April/early-May to mid-October (i.e., irrigation season).
[o] Low = low-flow period from mid-October to late-April/early-May.

The two sites where cattle management BMPs did not improve water quality were the IMP site in the IFC Watershed and the SPS site in the WHC Sub-watershed. At the IMP site, it was likely that the potential benefits of the BMP on water quality were masked because the 4-ha area of the BMP was at the outlet of a much larger sub-basin of 1387 ha. At the SPS site, the rotational grazing was ineffective likely because the pasture remained overstocked, and in fact, the stocking rate increased during the post-BMP period. Although not statistically significant, the water quality at the SPS site trended towards improvement in most parameters.

Of the five BMP sites that involved field-nutrient management, four were effective at improving water quality (Table 7.5). The water quality improvements occurred in WHC Sub-watershed (WFD and NFD) and at the two irrigated field sites (BDF and LLB). For the four effective BMPs, edge-of-field monitoring at eight monitoring stations revealed that one to four of the main water quality parameters (TN, TP, TSS, and *E. coli*) were significantly improved. But, at the same time, four of the eight edge-of-field monitoring stations had a significant concentration increase in one of the main water quality parameters.

For the two BMPs where there was more than one monitoring station (NFD and BDF), results varied. For example, Station 310 in the NFD showed the most significant improvements of both stations, but Station 311 in the NFD did not have the same trends as Station 310.

The BDF BMPs were effective at all four edge-of-field monitoring stations particularly for ON, *E. coli*, and to a lesser extent P. Hence, the BMP of no manure application at the BDF was considered effective even though overall improvement could not be measured instream. The volume of irrigation water from the Picture Butte reservoir in the Battersea Drain diluted the runoff that occurred from the edge-of-field during the irrigation season. However, during the non-irrigation season when flow in the drain was low, ON and electrical conductivity concentrations were significantly reduced in the post-BMP period as well as trends of reduced TN, NO_3-N, and NH_3-N concentrations. This suggests that the cessation of manure application reduced the leaching potential of N and salts into the shallow groundwater, which discharged into the drain during the low-flow period.

The least effective nutrient BMP was at the SFD site, and this was probably caused by the poor BMP implementation due to unavailability of manure injection equipment and inappropriate field conditions for establishing a vegetative buffer.

For the BMPs that were effective at improving water quality, as determined by edge-of-field monitoring, concentration reductions of TN, TP, TSS, or *E. coli* ranged from 2 to 85% (Table 7.6) during runoff events. The significantly improved concentrations post-BMP at the edge-of-field 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}. As previously discussed, these measurements reflect the scale or location of measurement, as post-BMP nutrient concentration ranges were generally lower at the instream monitoring sites (e.g., WIN and NPS sites) than at the edge-of-field (e.g., LLB or WFD sites) (Tables 7.6 and 7.7).

Table 7.6. Percent reduction and post-BMP concentrations during runoff events for the six edge-of-field monitoring stations where the BMPs were effective at improving water quality.

	Total N		Total P		TSS		*E. coli*	
BMP site	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]	13	6.65	24	3.77	nr[v]	39	56	643

[z] nr = no reduction.
[y] Monitoring Station 310.
[x] Data from 2009 were not included. Data are rainfall and irrigation runoff during the growing season.
[w] Average of monitoring Stations 203, 204, 205, and 206. Data are rainfall and irrigation runoff during the growing season.
[v] Monitoring Station 204 had a reduction of 65%, but the remaining stations had an increase in TSS.

Table 7.7. Paired differences (diff.) between (downstream minus upstream) monitoring stations[z] and post-BMP average concentrations (conc.) for three sites that showed the BMPs were effective at improving water quality.

	Total N			Total P			TSS			*E. coli*		
	Pre-BMP diff.	Post-BMP diff.	Post-BMP conc.[y]	Pre-BMP diff.	Post-BMP diff.	Post-BMP conc.[y]	Pre-BMP diff.	Post-BMP diff.	Post-BMP conc.[y]	Pre-BMP diff.	Post-BMP diff.	Post-BMP conc.[y]
BMP site	----- (mg L^{-1}) -----			----- (mg L^{-1}) -----			----- (mg L^{-1}) -----			--- (mpn 100 mL^{-1}) ---		
PST-corral	+6.0	-0.86	9.84	+1.30	-0.05	1.95	+17	+7	31	+9152	+313	789
WIN	+0.26	-0.18	2.62	+0.04	-0.10	0.46	+34	-108	198	+444	+198	809
NPS	+0.17	-0.09	3.68	+0.02	-0.02	0.93	+5	-3	6	+2465	-7769	3994

[z] The four parameters at the three sites showed a reduction between pre- and post-BMP differences, and this indicated the BMP had a positive influence on water quality.
[y] Post-BMP concentration for the downstream monitoring station: Station 9 for PST, Station 11 for WIN, and Station 302 for NPS.

7.3.2 Cumulative Effect of BMPs on Water Quality

It was not expected that the BMPs would have a cumulative effect on improving water quality at the outlet of the watersheds, primarily because of the relatively few BMPs that were implemented within each watershed. However, rather than observing no differences between the pre- and post-BMP periods, statistical analyses showed that water quality at the outlets during snowmelt and rainfall runoff tended to significantly deteriorate from the pre-BMP period to the post-BMP period (Table 7.8). The deterioration in water quality was primarily due to wetter years in the post-period. If water quality improvement at the outlet of a watershed is desirable, there would have to be efforts to implement a greater number of BMPs within the critical source areas of the watershed. Experimentally, it would have been desirable to have had similar hydrological and weather characteristics between the two periods to avoid confounding effects by these factors when evaluating BMPs in the field.

For the BMP Project, Jedrych et al. (2014a) used modelling techniques to simulate the application of BMP scenarios throughout the two watersheds to assess the cumulative effects on water quality at the watershed scale.

7.3.3 BMP Improvement on Riparian and Rangeland Quality

Water quality was the main environmental indicator to assess the effectiveness of BMPs at most of the study sites. However, at a few sites, the effects of BMPs on riparian and rangeland quality were also used as supplemental environmental assessment tools (Table 7.2). Riparian surveys were carried out at five sites and rangeland surveys were carried out at two sites. In addition, rangeland production was assessed at three sites.

The BMPs had a positive effect on riparian quality, particularly when cattle were completely excluded (IMP, OSW, DUG) or access was denied at certain times of the year through rotational grazing (PST and WIN) (Table 7.9). Rangeland quality was also improved when cattle access was controlled through rotational grazing (PST) or when cattle were excluded from a pasture area (FLT) (Table 7.9). This also translated into improved rangeland production at the PST site.

Rangeland production only increased when the BMP was designed to address high stocking densities. Rangeland production was not improved after BMPs were implemented at the NPS and SPS sites in the WHC Sub-watershed. Rotational grazing was adopted at the SPS site, but the main issue of high stocking density and over-grazing was not addressed. At the NPS site, rangeland production responded positively when grazing did not occur for 1 yr. However, the benefit of 1 yr of rest from grazing was lost after the cattle were returned to the pasture at a stocking density greater than the capacity of the pasture.

Table. 7.8. Average runoff concentrations and standard deviations (SD) of total nitrogen, total phosphorus, and total suspended solids for the pre-BMP and post-BMP periods at the outlets of Indianfarm Creek Watershed and Whelp Creek Sub-watershed.

		Total nitrogen		Total phosphorus		Total suspended solids	
		Average[y]	SD	Average	SD	Average	SD
Phase[z]	n	($mg\ L^{-1}$)					
				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 7.9. Summary of beneficial management practice (BMP) effects on riparian and rangeland quality.

Riparian survey assessment		Rangeland survey assessment		Rangeland production	
Site	BMP effective	Site	BMP effective	Site	BMP effective
PST - rotational grazing[z]	Yes	PST	Yes	PST	Yes
IMP - exclusion[y]	Yes	FLT	Yes	NPS	No
IMP - non-exclusion[z]	Yes - marginal			SPS	No
WIN - rotational grazing[z]	Yes				
OSW - exclusion[y]	Yes				
OSW - non-exclusion[z]	No				
DUG - exclusion[y]	Yes				
DUG - non-exclusion[z]	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.

7.3.4 Cost of BMPs

Beneficial management practices were implemented at 16 sites during the study (Table 7.2). The monetary cost of implementing and maintaining the BMPs ranged from $466 to $87,770 and labour ranged from 13 to 202 h (Figure 7.7). The BMP sites were broadly grouped into three BMP-type categories: cattle management, field-nutrient management, and surface-water management. For some sites, there was some overlap among these three groups. For example, surface-water management was the main focus at the FLT site, however, cattle management was also part of the BMP plan. Similarly, field-nutrient management was the main focus at the BDF and LLB sites, with surface-water management as part of the BMP plan. The cost of the bioengineering demonstration sites at the PST and WIN sites (PST-Bio, WIN-Bio) are shown separately in Figure 7.7. The cost of bioengineering was relatively high compared to 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 PST and WIN bioengineering, the average cost was $19,341 and 46 h labour per BMP site. The average monetary cost was driven by three sites (FLT, BDF, and LLB), which had much higher costs compared to the other sites. The median cost was slightly less than $12,000 per BMP site among all the sites. The median cost was moderately less for the field-nutrient management sites ($5775) compared to the cattle management sites ($6334). The surface-water management BMPs at the FLT and CAT cost $87,770 and $13,200, respectively. Only a portion of the suggested BMP plan was implemented at the CAT site (Sub-section 3.15), and the cost would have been much higher if the full plan had been implemented.

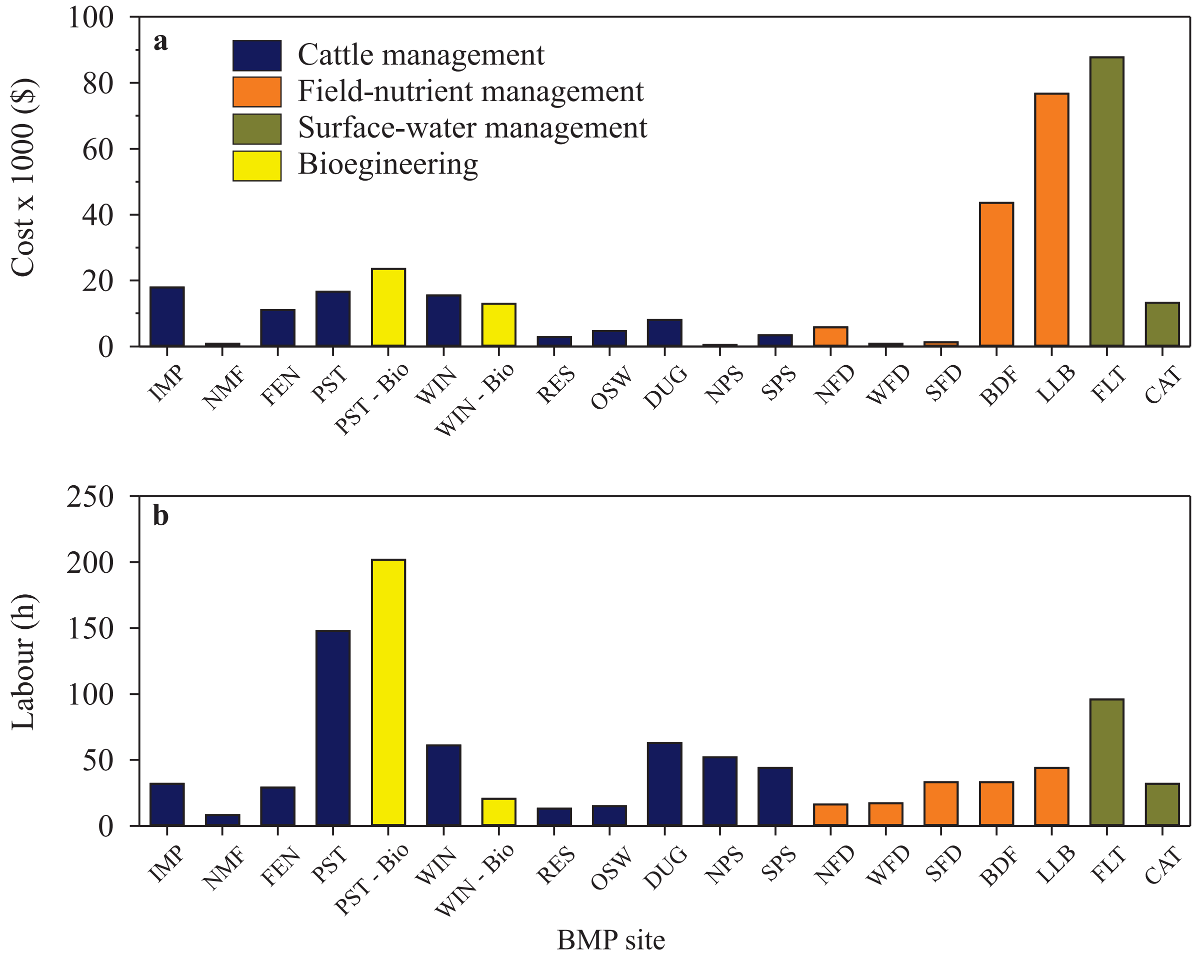


Figure 7.7. The (a) monetary and (b) labour costs for the implemented BMP sites.

Two of the field-nutrient management sites had irrigation systems (BDF and LLB), which were modified in order to reduce the amount of runoff generated from irrigation. The cost of modifications to the irrigation systems accounted for 19 to 30% of the total cost (Sections 5 and 6). This was not a potential cost at the other field sites as they were all rain-fed. The majority (69 to 78%) of cost at the BDF and LLB sites was due to hauling manure further distances. The BMP plans for these two sites included no application of any form of P because of the high STP concentrations. At the other three field-nutrient management sites (NFD, WFD, and SFD), STP concentration was only moderately high. The BMP recommendation at these three sites was to continue manure application in the post-BMP period, but at application rates that met the crop-removal rate of P. For these particular sites, there was no increase in manure-hauling cost for this BMP.

The majority of cost was generally a one-time cost to implement the BMP plans at most sites. This involved the construction of fences, relocation of feeding areas with wind breaks, removal of old corrals, and/or purchase of off-stream watering systems or other equipment. After the initial implementation, annual maintenance costs were minimal for the remainder of the BMP period during the study (2 to 3 yr). This was particularly true for the FLT site, which was the most expensive of the BMP sites (Figure 7.7). Eventually, equipment and infrastructure will need to be replaced at many of the sites. In addition, ongoing maintenance costs and management time that was not required prior to the BMPs, such as maintaining the rotational grazing BMPs at the PST, WIN, and SPS sites, also should be considered.

The cost distribution for the BDF and LLB sites was not the same compared to the other sites described above. As already indicated, the majority of cost for these two sites was for hauling manure further distances. The purpose of no manure application was to reduce the high STP concentration and thus reduce the risk of P loss in runoff water. However, the application of no manure for 3 to 4 yr during the study did not result in reduced STP concentration (Sections 5 and 6). Because of the build-up of a large pool of residual P in the soils at both sites, it will take many years to substantially reduce STP concentration through crop removal (at least >10 yr). Therefore, maintaining the BMP of no manure application will result in continued higher manure hauling costs for many years to come. Also, available crop N in the soil will likely become too low for optimum crop yield long before STP is substantially reduced, and therefore, will require the application, and cost, of added commercial N fertilizer.

It is difficult to provide general conclusions about the cost of BMPs. The main reason is that BMP plans, and hence the related costs, are site specific. In part, the level of cost depends on initial conditions. For example, at the PST and WIN sites, nearly all the fence required to establish riparian pastures and to practice rotational grazing already existed. If the fence had to be built to implement the BMP, the costs would have been much greater. The one-time up-front costs for BMPs are suitable for current cost-share programs like Growing Forward 2. This is in contrast to the BDF and LLB sites, which will have long-term costs in order to achieve the outcome of the BMP. Such long-term costs are not often supported by BMP-adoption programs.

The BMP costs summarized here, and in the Sections 3 to 6, are the total costs required to implement the BMP plans. The cost-effectiveness of BMPs in terms of net revenue or the net cost required to achieve a unit reduction in a water quality parameter (i.e., improved water quality), such as a reduction in concentration or load, was not determined for the BMP sites used in the field study. These types of analyses were carried out using modelling techniques by Jedrych et al. (2014a,b) as part of the overall project. The modelling aspect provided an economic assessment (cost effectiveness) for the BMP scenarios, and this provided a long-term perspective of investments and returns.

7.4 Water Quality from Agricultural Fields and Watersheds in Alberta

7.4.1 Water Quality from Agricultural Fields

Other than the BMP Project, there are limited studies in Alberta where water quality was monitored from agricultural fields. The Alberta Soil Phosphorus Limits Project (P Limits Project) examined water quality 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 manured fields was the LLB site, which was also monitored for the BMP Project.

Generally, there was an increase in TN and TP concentrations in runoff as fields were farmed and as manure was added (Figure 7.8 and Table 7.10). The pasture and non-manured sites had the lowest average nutrient concentrations when compared to the manured and heavily manured sites. The average TN concentration for the pasture and non-manured sites ranged from about 2 to 6 mg L^{-1} and TP concentration ranged from about 0.8 to 1.0 mg L^{-1}(Table 7.10). Applying manure to cultivated fields resulted in higher TN and TP concentrations in runoff water when compared to non-manured fields.

Manure accumulated through grazing as well as application on cultivated fields. At sites where extensive grazing practices occurred, water quality concentrations tended to be higher than water quality from the native range site of the P Limits Project (STV) as well as the sites where fall cattle grazed for the BMP Project (REF and NMF). At the fall grazed sites, the cattle often lingered in the drainage channels as evidenced by the higher fecal pats compared to the surrounding area.

The TN concentrations tended to be more variable than the TP concentrations and this was likely because N is more water soluble than P and N has a gaseous phase. As manure was added, the TN ratio of dissolved to organic N tended to increase. Similarly, with the addition of manure, the fraction of dissolved P in the runoff tended to increase (Figure 7.8).

The heavily manured LLB site was monitored in both studies. During the P Limits Project (2003 to 2005), the producer followed his normal manure application practices, which was to apply manure to a part or all of the two quarter sections every year. In between projects, manure was applied at the LLB site in 2006 and 2007. Then, the producer quit applying manure in 2008 for the duration BMP Project. Data in Figure 7.8 for the BMP Project represent the two pre-BMP years (2007 and 2008). Although data are not shown, if the post-BMP years (2009 to 2011) are included for the BMP Project in Figure 7.8, there is a clear reduction in nutrients in the runoff water following the cessation of manure application (Sub-section 6.3.8.2), and particularly for TP (dissolved P).

7.4.2 Water Quality from Agricultural Watersheds

There are about 446 watersheds in Alberta where agriculture is the predominant land use activity (Anderson et al. 1999; Table 7.11). These watersheds are within three distinct natural regions, namely the Boreal Forest (Dry Mixedwood Natural Subregion), Parkland, and Grassland (Figure 7.9).

In the BMP Project, the WHC Sub-watershed was representative of the typical high AI in the Parkland Natural Region. The IFC Watershed was in the Grassland Natural Region and had a moderate AI, and this was representative of this natural region, which had 45% of the watersheds classified as moderate AI (Table 7.11). The irrigated field sites (BDF and LLB) were also in the Grassland Natural Region and the fields were in watersheds with high AI.

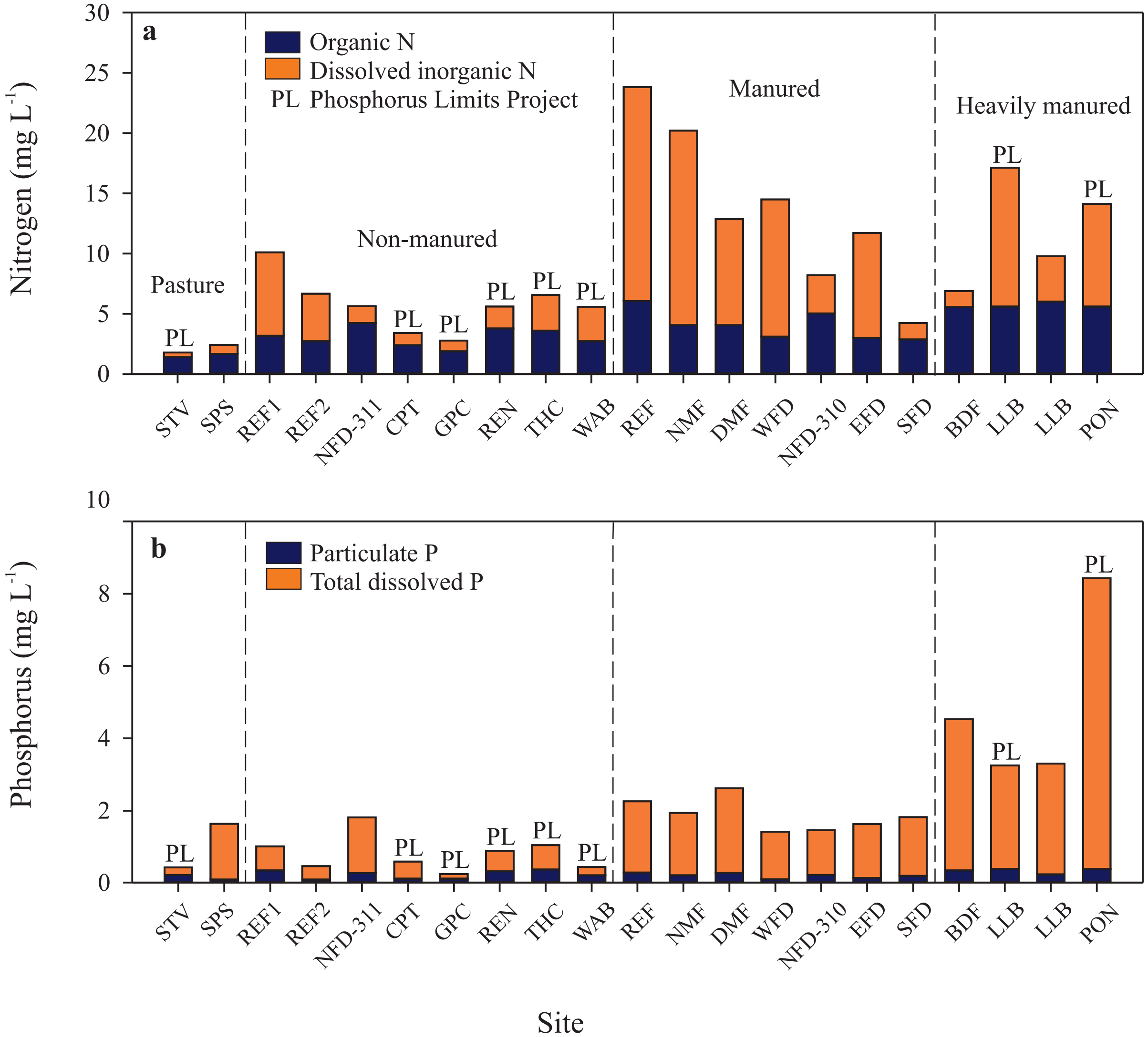


Figure 7.8. Average edge-of-field (a) total nitrogen (TN) and (b) total phosphorus (TP) concentrations for agricultural fields monitored in the Nutrient Beneficial Management Practices Evaluation and Alberta Soil Phosphorus Limits projects. Averages for the IFC, WHC, BDF, and LLB sites with implemented BMPs were based on the pre-BMP data. Averages for the Phosphorus Limits Project were based on the 2003 and 2005 data (2004 data were not included due to issues with TDP values). Note: Sites with PL are Phosphorus Limits Project sites. The LLB site was monitored in the same location for both projects.

Watershed size varies among the three natural regions. The Boreal Forest tends to have the largest watersheds with an average size of about 93,800 ha followed by the Parkland at 50,800 ha and the Grassland at 43,700 ha (Table 7.11).

Alberta Agriculture and Rural Development has conducted detailed water quality studies in many of Alberta's agricultural watersheds including watersheds from the Alberta Environmental Sustainable Agriculture (AESA) Water Quality Monitoring Program (Lorenz et al. 2008) and the BMP Project. The 23 watersheds used in the AESA Program ranged in size from 3,200 to 137,000 ha, and they were generally smaller than the average watershed size in their respective natural region. The sizes of the BMP Project watersheds were within the small range of the AESA watersheds in the Parkland and Grassland natural regions (Figure 7.9 and Table 7.12).

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 (Figures 7.10a and 7.11a). Land-cover differences may explain the observed water quality trends. Indianfarm Creek had considerably higher cultivated cropland cover (39%) than Meadow Creek (7%) and Trout Creek (<1%). Further, Trout and Meadow creeks had much higher

Table 7.10. Average concentration of total nitrogen and total phosphorus in runoff water for the main edge - of-field group types from the Nutrient Beneficial Management Practices (BMP) Evaluation Project and the Soil Phosphorus Limits Project.

Edge-of-field group[z]	Number of sites	Total nitrogen[y] (mg L^{-1})	Total phosphorus[y] (mg L^{-1})
Pasture	2	2.11*b*	1.03*c*
Non-manured	8	5.79*b*	0.81*c*
Moderately manured	7	14.0*a*	1.90*b*
Heavily manured	4	12.2*a*	4.87*a*

[z] The post-BMP data were not included for the SPS, NFD-311, NMF, WFD, NFD-310, SFD, BDF, and LLB sites from the BMP Project.
[y] Averages followed by different letters are significantly different ($P < 0.1$).

Table 7.11. Number of agricultural streams and average watershed size in the Boreal Forest, Parkland, and Grassland natural regions stratified by agricultural intensity (AI) (Anderson et al. 1999).

Natural region	Number of streams	Average watershed area (ha)	High AI[z]	Moderate AI	Low AI
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.

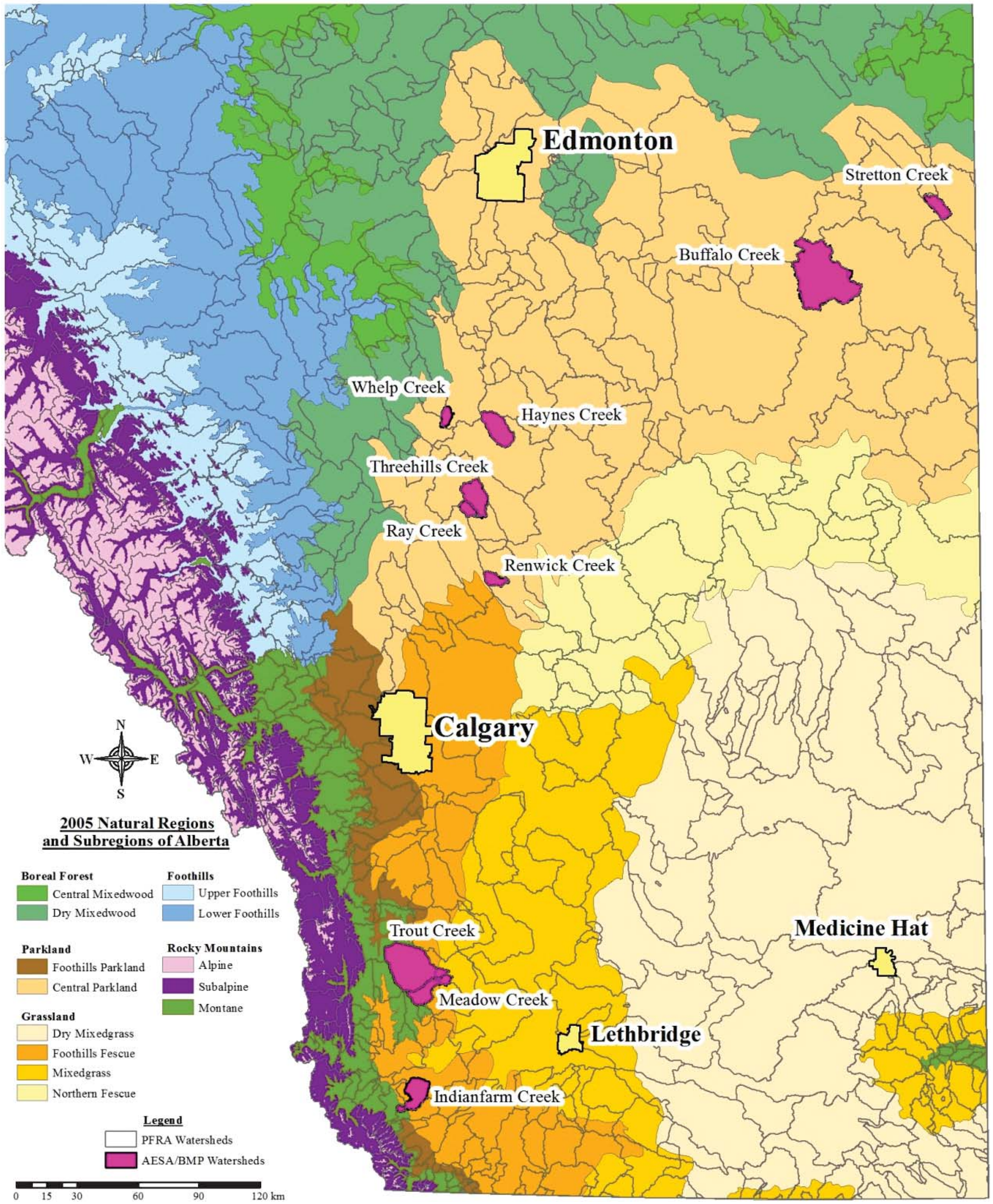


Figure 7.9. Location of the Beneficial Management Practices (BMP) Project watersheds (Indianfarm Creek Watershed and Whelp Creek Sub-watershed), and eight Alberta Environmentally Sustainable Agriculture (AESA) Water Quality Project watersheds, which are located in the Parkland and Grassland natural regions.

permanent cover (68 to 78% grass/forage; 16 to 32% trees/shrubs) than IFC (56% grass/forage; 4% trees/shrubs). The Whelp Creek Sub-watershed had significantly different TN and TP concentrations than the AESA watersheds in the Parkland Natural Region (Figures 7.10b and 7.11b), with Whelp Creek having the second highest concentrations after Haynes Creek. Unlike the Grassland watersheds, land cover does not explain the observed water quality trends in the Parkland Natural Region and an explanation for the observed pattern is unknown.

The ratios of ON:TN and PP:TP in the BMP Project watersheds were generally comparable to the AESA watersheds in their respective natural region (Figures 7.10 and 7.11), although Indianfarm Creek tended to have high portions of ON and PP than the comparable Trout and Meadow creeks. This may also be the result of the land-cover differences discussed above for the three Grassland watersheds.

Generally, 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 the patterns observed by Lorenz et al. (Figure 7.12). However, the WHC Sub-watershed hydrograph also showed a runoff peak in early July, but this was an anomaly representing the atypical rains in 2011.

Recommendations for BMPs within watersheds can be provided on the basis of natural regions, given that runoff, water quality, and land-use patterns are generally consistent in the regions. Since the BMP Project watersheds are fairly representative of similar watersheds in their natural areas, many of the BMPs that were employed for the project could likely be employed elsewhere in their respective natural regions. For the Grassland watersheds, BMPs should target particulates during the spring rains. Many of the BMPs in the Grassland watersheds may involve extensive livestock and field erosion. For the Parkland watersheds, BMPs should target dissolved inorganic nutrients in snowmelt. Many of the BMPs in the Parkland Natural Region may involve intensive livestock manure management.

Table 7.12. Size of the Alberta Environmentally Sustainable Agriculture Water Quality Project watersheds in the Parkland and Grassland natural regions (Lorenz et al. 2008) compared to the Indianfarm Creek and Whelp Creek watersheds.

Natural region	Watershed	Area (ha)
Parkland[z]	Buffalo Creek	71,400
	Threehills Creek	19,900
	Haynes Creek	16,600
	Stretton Creek	7,400
	Renwick Creek	5,900
	Whelp Creek	5,056
	Ray Creek	4,440
Grassland[z]	Trout Creek	44,100
	Indianfarm Creek	14,145
	Meadow Creek	13,000

[z] The Parkland Natural Region watersheds have a high agricultural intensity while the Grassland Natural Region watersheds are moderate intensity.

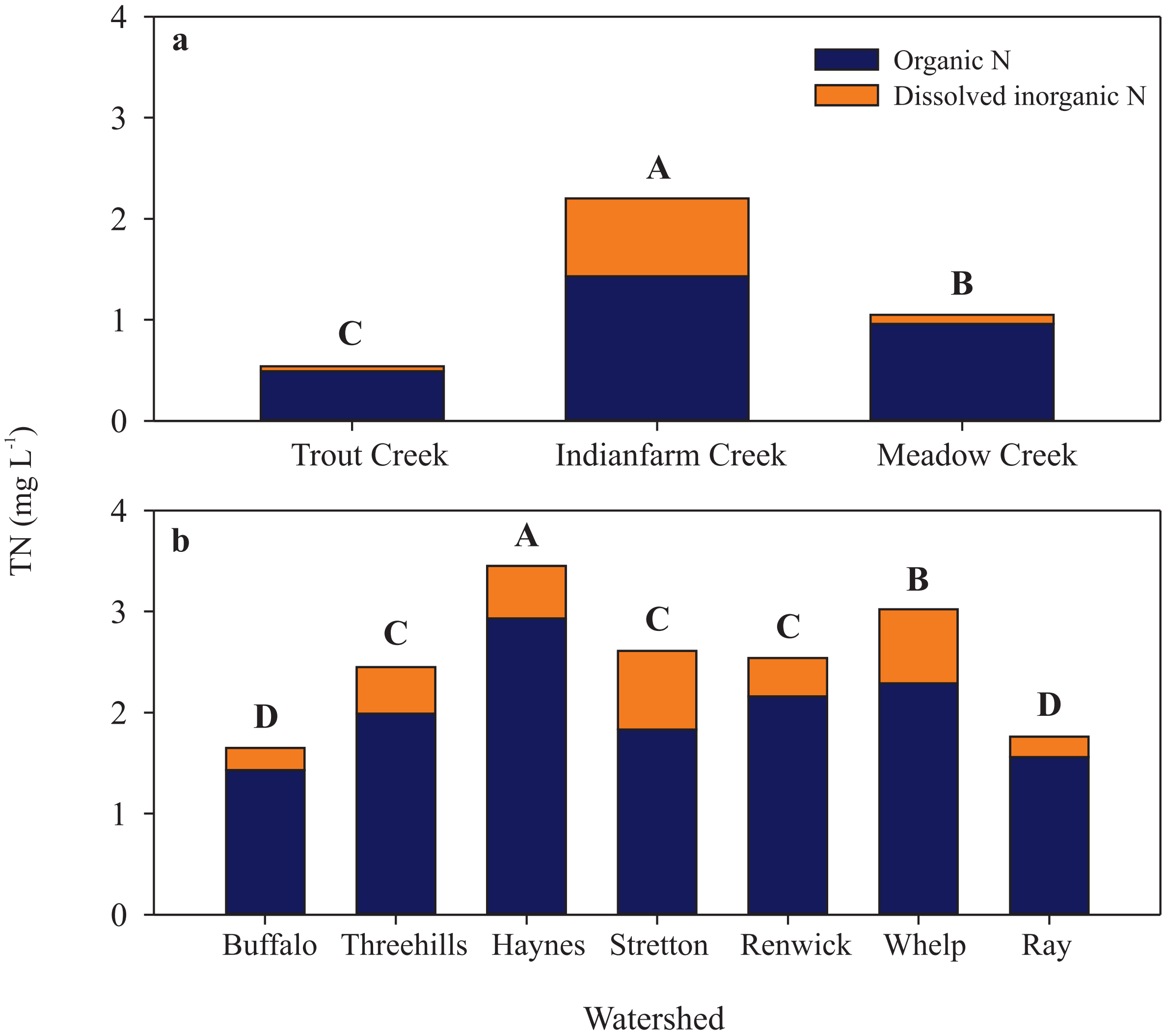


Figure 7.10. Average total nitrogen (TN) concentrations at the outlets for (a) Grassland watersheds with moderate agricultural intensity and (b) Parkland watersheds with high agricultural intensity. Watersheds are in order of increasing size from left to right. Averages were determined from 2007 to 2012 data for Indianfarm Creek Watershed and from 2008 to 2012 data for Whelp Creek Sub-watershed. Averages were determined from 1995 to 2007 data for the other watersheds (Lorenz et al. 2008). Bars (for TN) with the same capital letter are not significantly different (*P*<0.1). Note: No water quality data were collected in 1998 from Meadow, Trout, and Buffalo creeks; in 2004 from Haynes Creek; and in 2001, 2002, and 2003 from Stretton Creek.

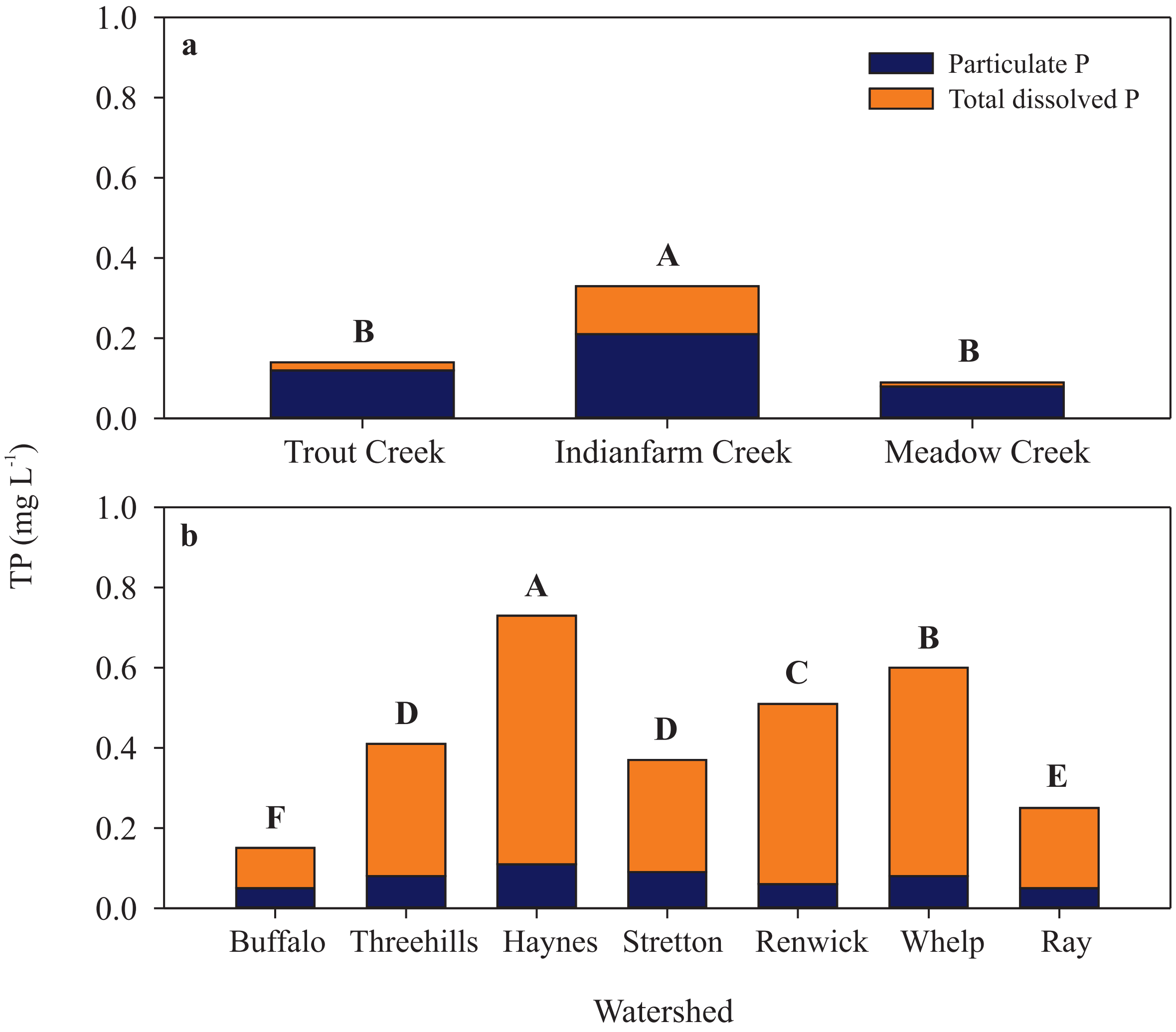


Figure 7.11. Average total phosphorus (TP) concentrations at the outlets for (a) Grassland watersheds with moderate agricultural intensity and (b) Parkland watersheds with high agricultural intensity. Watersheds are in order of increasing size from left to right. Averages were determined from 2007 to 2012 data for Indainfarm Creek Watershed and from 2008 to 2012 data for Whelp Creek Sub-watershed. Averages were determined from 1995 to 2007 data for the other watersheds (Lorenz et al 2008). Bars (for TP) with the same capital letter are not significantly different (*P*<0.1). Note: No water quality data were collected in 1998 from Meadow, Trout, and Buffalo creeks; in 2004 from Haynes Creek; and in 2001, 2002, and 2003 from Stretton Creek.

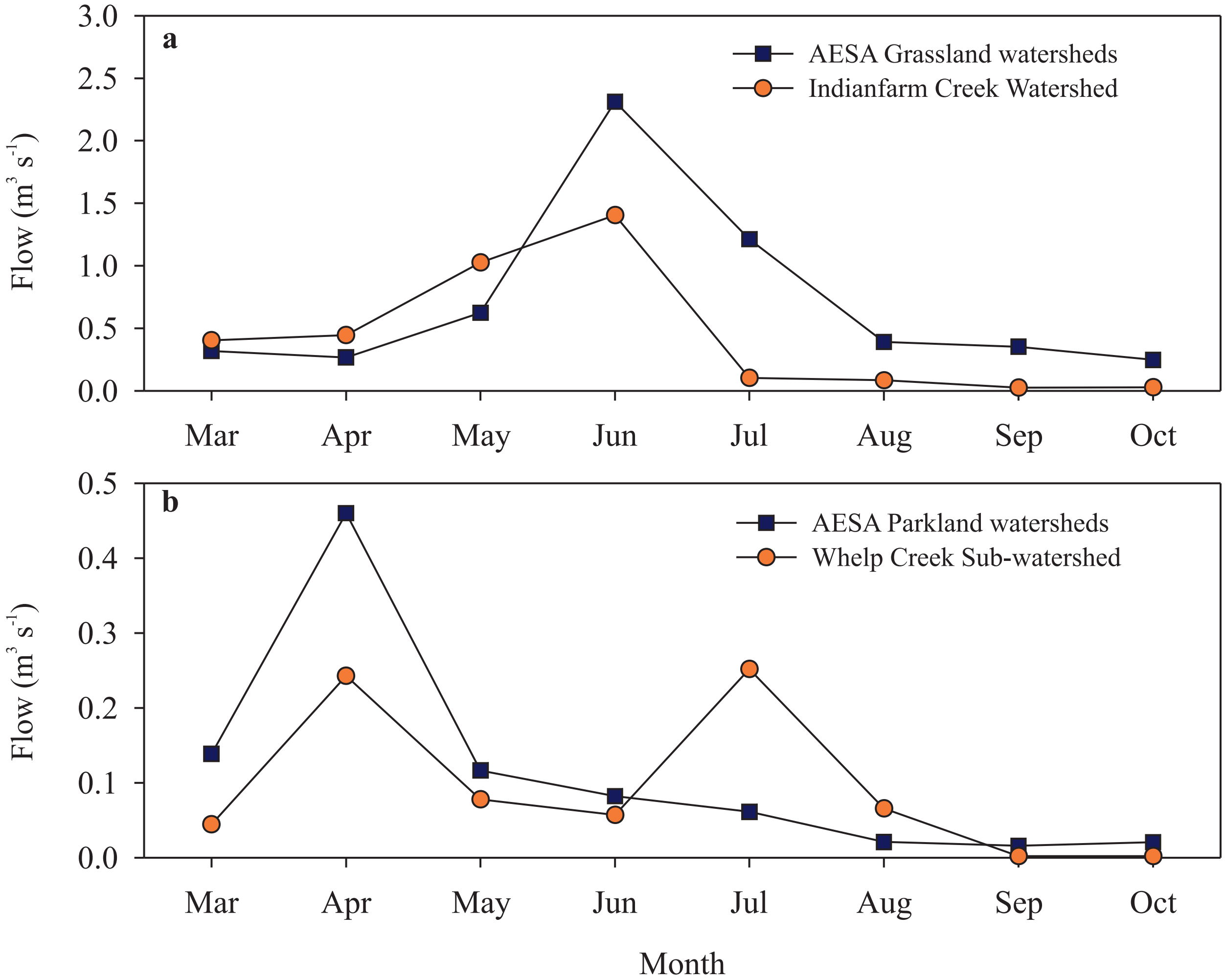


Figure 7.12. Monthly average flows at the outlets of the (a) Alberta Environmental Sustainable Agriculture (AESA) Grassland watersheds (Meadow and Trout creeks; 1995 to 2007) and Indianfarm Creek Watershed (2007 to 2012), and (b) AESA Parkland watersheds (Buffalo, Threehills, Haynes, Stretton, Renwick, and Ray creeks; 1995 to 2007) and Whelp Creek Sub-watershed (2008 to 2012).

7.5 Summary and Key Findings

Beneficial management practices were implemented in suites at sites based on the identification of environmental concerns with livestock, field nutrient, and/or surface water (including irrigation) management. The BMPs were site specific and included a comprehensive approach developed in cooperation with the producers. Beneficial management practices were implemented at 16 sites, and water quality data were used to evaluate BMP effectiveness for 11 of the sites. In addition, BMPs were evaluated based on soil nutrient status as well as riparian and rangeland quality at some sites. The costs of BMP implementation were also tracked.

- There were challenges in implementing the BMPs. When issues arose, flexibility was required to develop a different plan, or in many cases, the BMP could not be fully implemented as it was designed.
    - Challenges included poor weather and difficult field access (SMF, DMF), untimely access to manure-spreading equipment from contractors (NFD, SFD), producers not willing to implement or maintain a portion of the BMP plans (NFD, CAT, BDF), and technical difficulties with irrigation equipment (BDF and LLB).
    - There were also challenges trying to anticipate management changes, which could be driven by crop and inorganic fertilizer prices year-to-year. For example, the two reference sites in WHC Sub-watershed (REF1 and REF2) were selected for monitoring to obtain water quality from non-manured annually cropped fields. However, both fields received a one-time application of liquid manure in fall 2008 as a result of high inorganic fertilizer costs.
- Almost all of the BMP suites implemented at the sites were found to be effective (eight sites) at significantly improving water quality in terms of TN, TP, TSS and/or *E. coli* concentrations. For those sites where water quality did not improve (three sites), the BMP plan was often not implemented as designed.
    - Cattle management BMPs were likely to show short-term immediate water quality improvement; whereas, nutrient management was a long-term and continuous improvement scenario. A monitoring time frame of a few years may be sufficient to capture environmental benefits for some BMPs like cattle management changes, although it depends on the variability of the weather, management practises, and expected response times.
    - Of the six BMP sites that involved cattle management, four were effective at improving water quality. For the two sites that did not have significant improvements, one site (SPS) was trending towards improvement and any possible positive results at the other site (IMP) were likely masked due to the size of the contributing area.
    - Of the five BMP sites that involved field-nutrient management, four were effective at improving water quality. For the one site (SFD) that did not have significant improvement, the BMP was poorly implemented due to unavailability of manure injection equipment and inappropriate field conditions for establishing a vegetative buffer.

  - For the BMPs that were effective at improving water quality, concentration reductions ranged from 2 to 85% during runoff events. The significantly improved concentrations for the post-BMP at the edge-of-field remained relatively high.
  - In addition to water quality, the BMPs had a positive effect on riparian and/or rangeland quality, particularly when cattle were completely excluded (IMP, OSW, DUG) or access was denied at certain times of the year through rotational grazing (PST, WIN, PST, and FLT). The change to grazing practises also improved rangeland production at the PST site.
- With the addition of manure, from either grazing or manure application, TN and TP concentrations were significantly higher in runoff water than water from non-manured or pasture sites. The edge-of-field concentrations for sites that might be considered as 'background' or 'reference' were much higher than concentrations that would be measured instream.
  - For the pasture and non-manured (inorganic fertilizer) sites, the average TN concentration ranged from about 2 to 6 mg L^{-1} and TP concentration ranged from about 0.8 to 1.0 mg L^{-1}. These values reflect farm management on native grass, pastureland, and cultivated fields that received only inorganic fertilizer.
  - Sites with manure application (pre-BMP) had average TN concentrations that ranged from about 12 to 14 mg L^{-1} and average TP concentrations that ranged from about 2 to 5 mg L^{-1}. After the implementation of BMPs, most of the sites had statistically significant concentration reductions in one or both nutrients.
- This study demonstrated that the location or scale at which water quality is measured has important implications on the expected nutrient concentration. Generally, the smaller the scale, the higher the concentration of nutrients expected. So, nutrient concentrations were highest from edge-of-field > tributary > mainstem of a stream.
  - Water quality concentrations are often used to assess BMPs. Measuring water quality at a smaller scale like the edge-of-field rather than instream improved the likelihood of measuring a successful environmental response caused by BMPs.
- The monetary cost of implementing and maintaining the BMPs ranged from $466 to $87,770 and labour ranged from 13 to 202 h. The median cost for the suite of BMPs implemented at the 16 sites was about $12,000 per site. The majority of cost was generally a one-time up-front cost to implement the BMP. The most costly BMPs involved surface-water management and manure hauling. Bioengineering was also relatively expensive at the PST and WIN sites.
  - The surface-water management BMPs at the FLT and CAT cost $87,770 and $13,200, respectively. At both these feedlots, surface water was diverted away from the pens. At the FLT site, berms were constructed around the catch basin and the dugout.
  - Riparian bioengineering was implemented at two sites in IFC at an average cost of about $18,000. Bioengineering was particularly labour intensive, which was reflected in the price of the contract work.

- Fields with a long-term accumulation of soil P will likely take decades to reduce P concentration. Field-nutrient management BMPs were costly when there was a requirement to haul manure due to high soil nutrients (i.e., STP). If the BMP is to be effective, it would need to be implemented for the long-term, and this would be concerning given the cost. And, current BMP funding support programs do not have long-term funding.
    - At the LLB site, the cost to haul manure 7.5 km was $30,000. The manure was intended for application on two quarter sections. If the BMP of manure cessation continued at LLB, the cost of manure transport would be borne on an annual basis and the hauling cost may increase as soils near the feedlot reach agronomic STP concentrations, thereby requiring the manure to be hauled a further distance.
    - Likely, only a very small part of the province is at risk of high soil nutrients due to manure application. The at-risk areas will be where there is a high intensity of relatively large CFOs. 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 risk to surface water contamination and, if present, shallow groundwater.
    - For the BDF and LLB sites, the focus should be on reducing the soil STP levels to or below agronomic requirements, recognizing that it will take decades to be able to measure changes in the soil profile. Realistically, however, the cost of manure transportation will continue to be an impediment if it must be borne by producers for the long term.
    - Efforts should also include reducing irrigation runoff at the BDF and LLB sites, as the average annual proportion of total runoff due to irrigation at the two study sites was 37 to 43%.
- A key proactive action to protect water quality will be to avoid the build-up of soil nutrients. With the addition of manure through grazing or application, nutrients can quickly accumulate in the soil. Fields with a slight accumulation of soil nutrients can be reduced within a few years with BMPs. Particular attention should be given to hotspots that can develop within fields if manure or livestock are confined to a small area.
    - At the DMF site, dairy manure was applied at very high rates, but to only a few hectares in a given year. With time, this practice resulted in P accumulation to more than 120 mg kg^{-1} on average. Similarly, the corral area (PST-corral) had a relatively high STP concentration, at slightly more than 100 mg kg^{-1} and was particularly affected by congregating of cattle, which resulted in high densities of fecal pats in this area compared to the rest of the pasture.
    - The residual accumulation of organic P from manure will maintain STP concentrations for several years after manure application is stopped. Therefore, regular soil testing should be practiced to monitor potential soil P accumulation.
    - Although it has high agricultural intensity with several CFOs, the WHC Sub-watershed generally had soil nutrients that were only slightly above or below agronomic levels. Continued application of manure at or below crop uptake may be sufficient for environmental risk mitigation.

- Recommendations for BMPs within watersheds can be provided on the basis of natural regions, given that runoff, water quality, and land-use patterns are generally consistent in the regions.
  - For the Grassland Natural Region watersheds, BMPs should target particulate concentrations during the spring rains. Many of the BMPs in the Grassland watersheds may involve extensive livestock (i.e., grazing) and field erosion.
  - For the Parkland Natural Region watersheds, BMPs should target dissolved inorganic nutrient concentrations in snowmelt. Many of the BMPs in the Parkland Natural Region may involve intensive livestock manure management.
  - The BMPs that were implemented for water quality improvements were rarely designed to reduce flows, but rather, the BMPs targeted concentration reductions. 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, if load and export reductions are needed, flow reduction may need to be targeted.
- Because only a few BMPs were implemented in relatively large watersheds, there is still a gap in understanding the cumulative benefit of implementing BMPs in effort to improve water quality at a watershed scale. Further, desired end states or water quality objectives for the edge-of-field and the outlets of agricultural watersheds need to be defined.
  - Even though the modelling component (Jedrych et al. 2014a,b) of the BMP Project investigated the cumulative effects of BMPs, further work is required for on-the-ground validation of cumulative BMPs in improving water quality.
  - It will be important to develop site-specific nutrient objectives in consideration of scale. Alberta Environment and Sustainable Resource Development have recently (2014) revised provincial water quality guidelines. The surface water quality guideline is a narrative for 'other water bodies', and states that "… nitrogen (total) and phosphorus concentrations should be maintained so as to prevent detrimental changes to algal and aquatic plant communities, aquatic biodiversity, oxygen levels, and recreational quality. Where priorities warrant, develop site-specific nutrient objectives and management plans." (ESRD 2014).