3 INDIANFARM CREEK WATERSHED

3.1 Introduction

3.1.1 Watershed Description

Indianfarm Creek (IFC) Watershed is approximately 100 km west of Lethbridge, Alberta (Figure 3.1). 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. This represented the drainage area to Station 1 (i.e., the study outlet), and was slightly smaller than the area (14,502 ha) of the whole watershed (Sub-section 2.5.1).

Indianfarm Creek Watershed lies in the Foothills Fescue Natural Sub-region (Natural Regions Committee 2006), which is in a relatively high precipitation zone of Alberta and the topography is considered well-drained. The 30-yr average (1971 to 2000) annual precipitation for the area is 515 mm (Environment Canada 2013), 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. 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 3.2). 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.

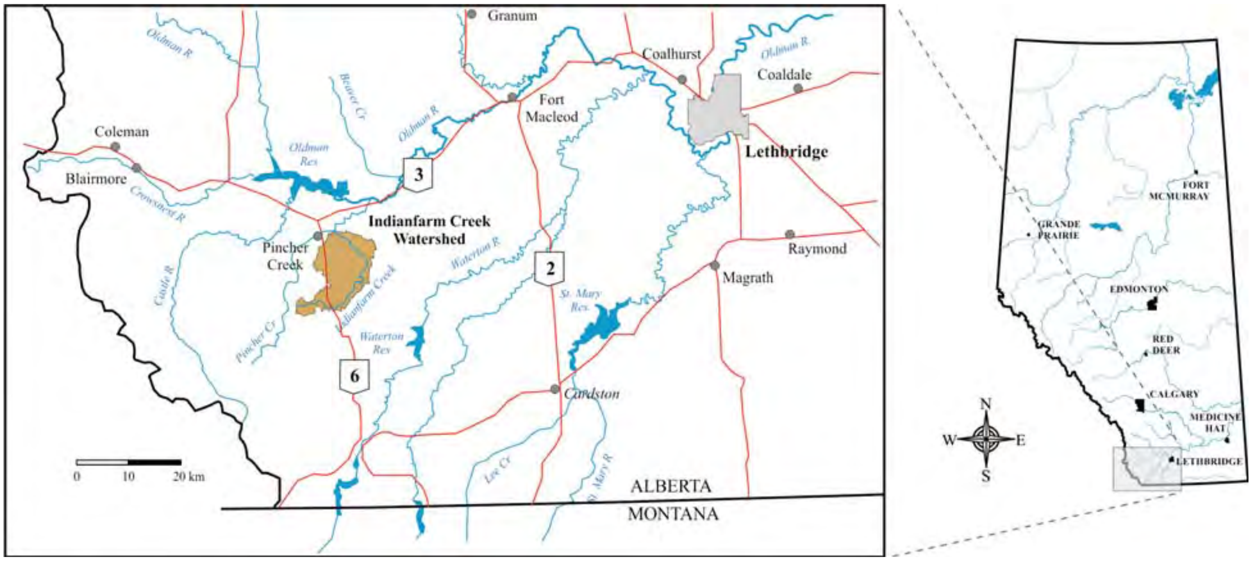

Figure 3.1. Location of the Indianfarm Creek Watershed in southwestern Alberta.

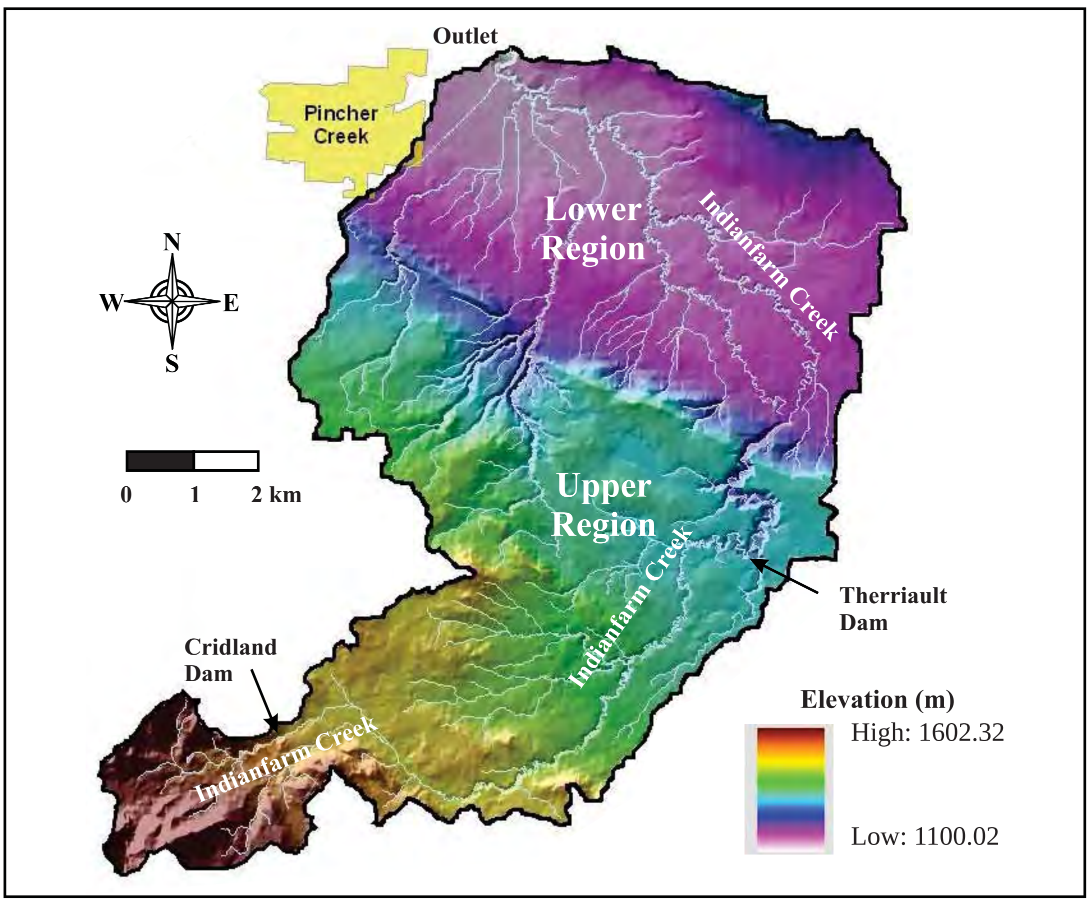

Figure 3.2. Topography and elevation of the Indianfarm Creek Watershed.

The major water channel within the watershed is Indianfarm Creek, which is an incised and meandering creek that flows from south to north (Figure 3.2). Smaller 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. Although IFC is considered ephemeral and primarily driven by snowmelt and rainfall events, the flow can be regulated by Therriault Dam, which is in the southern region of the watershed (Figure 3.2). During low-flow months, when water is required by downstream users (e.g., to water livestock), water is released from the dam. Depending on the weather, this may occur several times per year, usually in late summer or fall. In addition, Cridland Dam may also influence flow in the southwest portion of the watershed, and is upstream from Therriault Dam (Figure 3.2).

Agriculture is the primary land-use practice in the watershed with crop and livestock production dominating the landscape. Annual crop production is primarily barley with some wheat, canola, and oat production. There is a significant amount of forage produced, along with native range and tame pasture used for cow-calf production. Aside from crop production, livestock production is the other major agricultural component in the IFC Watershed, including beef cattle confined feeding operations, several cow-calf operations, and one dairy operation. In 2007, there were approximately 80 landowners with 60 active agricultural producers in the watershed.

3.1.2 Beneficial Management Practices Sites

Twelve BMP sites were established in the Indianfarm Creek Watershed (Figures 3.3 and 3.4). 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), Feedlot (FLT), Off-stream Watering (OSW), Dugout (DUG), and Catch Basin (CAT) sites. Most of the BMP sites were in the lower region of the watershed. Of the 12 BMP sites, eight sites focused on cattle management (DUG, FEN, IMP, NMF, OSW, PST, REF, and WIN), two sites focused on manure nutrient management (DMF and SMF), and two sites focused on surface-water management (FLT and CAT). Cattle management was also part of the BMP plan at the FLT site. More details about these sites are presented later in this section.

3.2 Weather

3.2.1 Methods

Annual and 30-yr average (1971 to 2000) data were obtained for the nearby Environment Canada weather station at Pincher Creek from AgroClimatic Information Services (ARD 2013b) (Sub-section 2.4).

The Pincher Creek AUT station was relatively close, but outside of the watershed and was not able to provide any indication of variation within the watershed. Consequently, four weather stations were established within the watershed in June and July 2008 to obtain site specific data and determine variability within the watershed. The four stations were roughly spaced at 100-m elevation intervals. Indianfarm Creek Weather Station 1 (IWS1) was at the lowest elevation near Water Monitoring Station 9 and IWS4 was at the highest elevation 5.6 km west-southwest of Water Monitoring Station 20 (Figure 3.3). Indianfarm Creek Weather Station 2 (IWS2) was near Water Monitoring Station 17 and IWS3 was near Water Monitoring Station 20. Further description of the weather stations is in Sub-section 2.4.2.

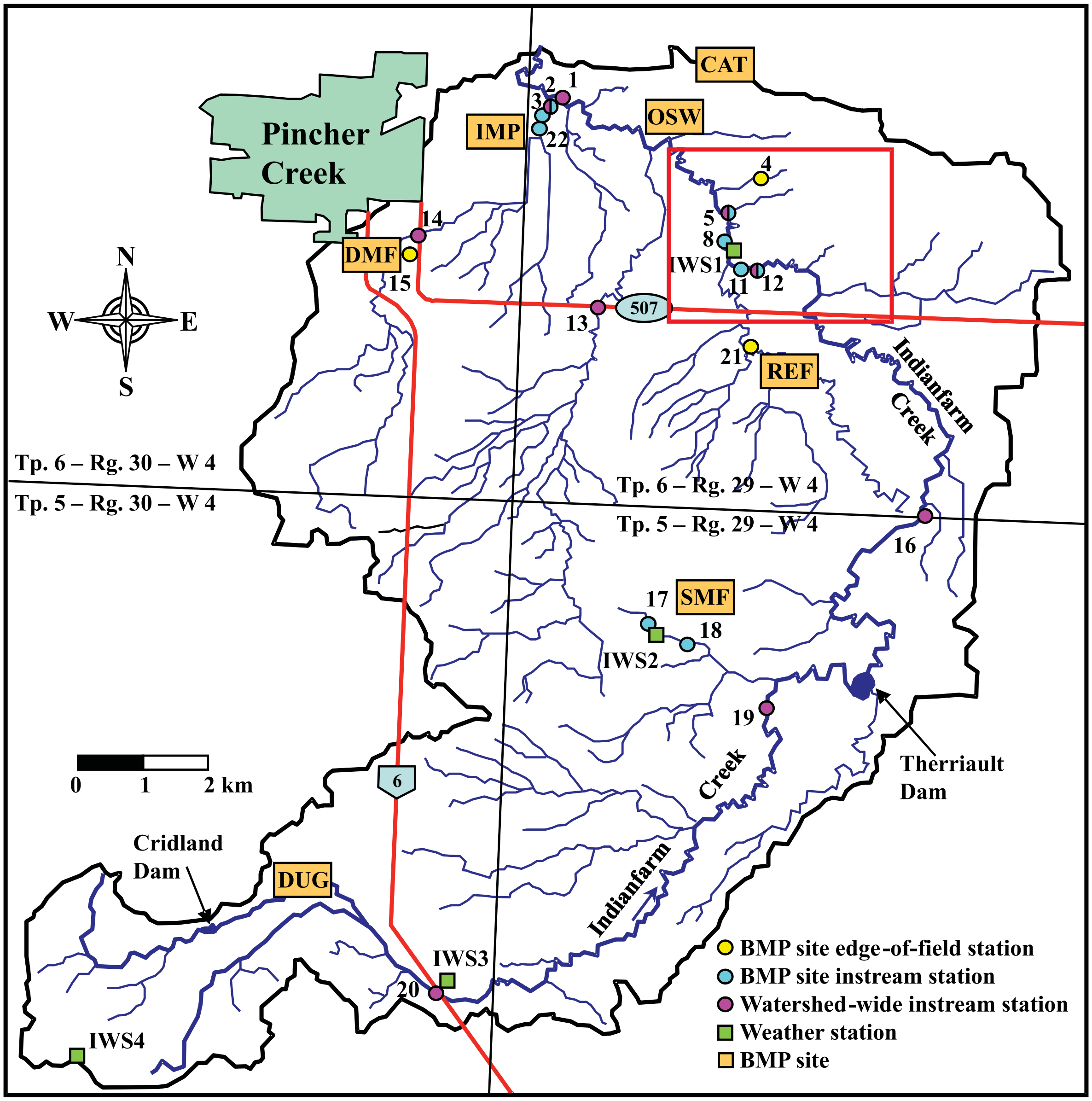

Figure 3.3. Location of the Impoundment (IMP), Dairy Manure Field (DMF), South Manure Field (SMF), Reference (REF), Off-stream Watering (OSW), Catch basin (CAT), and Dugout (DUG) sites with associated water monitoring stations, watershed-wide monitoring stations, and weather stations. A more detailed view of the red-boxed area is in Figure 3.4.

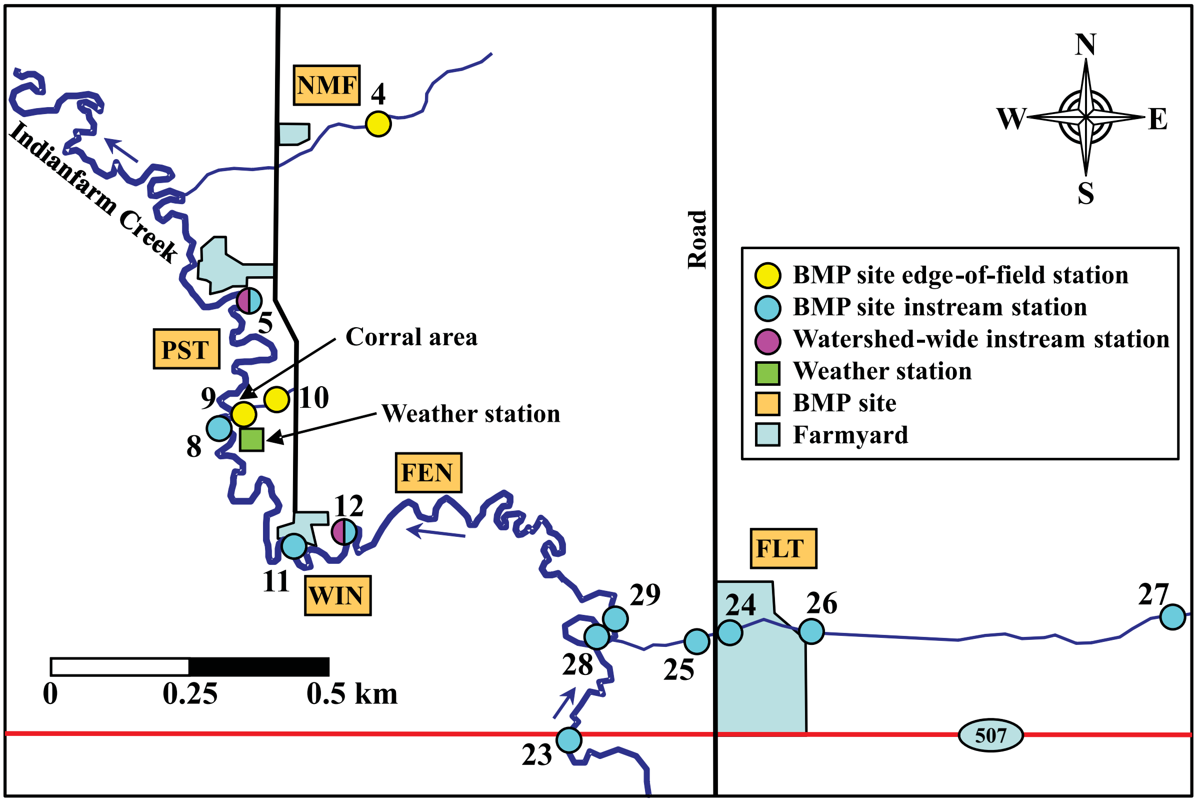

Figure 3.4. Location of North Manure Field (NMF), Pasture (PST), Wintering (WIN), Fencing (FEN), and Feedlot (FLT) BMP sites and associated water monitoring stations.

3.2.2 Results and Discussion

During the project from 2007 to 2012, monthly average daily temperatures in IFC Watershed were generally similar to 30-yr averages (Table 3.1). The warmest year was 2007 for the annual average temperature and the growing season (May to September) average temperature. July 2007 had the highest average daily temperatures during the project, well above the 30-yr average. Overall, 2009 was the coldest year for annual mean temperatures, with nine months colder than 30-yr average values. However, the average temperature during the 2009 growing season (May to September) was similar to the 30-yr average. The growing season with the coolest average temperature was in 2010.

The driest year was 2007 with 34% less total annual precipitation compared to the 30-yr average (Table 3.2). Nearly every month in 2007 had lower than average precipitation, except for September. In contrast, total annual precipitation from 2008 to 2011 ranged from 4 to 32% greater than the 30-yr average. The wettest year was 2010. Much of the above-average precipitation in 2010 occurred as rain from April to June and to a lesser extent from July to September. Overall, the study period was slightly above the 30-yr average in terms of annual and growing season precipitation.

Table 3.1. Monthly, annual, and growing season average daily temperature from 2007 to 2012 and 30-yr (1971 to 2000) average values for the Pincher Creek AUT weather station (ARD 2013b).

Time period	2007	2008	2009	2010	2011	2012	2007-2012 average	30-yr average
	(°C)							
January	-3.5	-6.4	-4.7	-4.2	-8.2	-4.3	-5.2	-6.7
February	-5.6	-2.9	-4.8	-1.8	-9.0	-3.6	-4.6	-4.3
March	3.4	0.1	-3.0	3.4	-4.2	0.9	0.1	-0.5
April	3.9	2.1	3.6	4.2	1.5	5.7	3.5	4.7
May	10.0	10.0	9.4	6.2	8.0	9.2	8.8	9.6
June	13.7	13.0	12.2	12.6	12.3	12.8	12.8	13.6
July	21.3	16.8	16.0	15.5	16.6	17.6	17.3	16.5
August	16.1	16.6	15.0	14.6	17.1	16.7	16.0	16.2
September	10.8	11.7	14.1	9.5	14.2	13.6	12.3	11.3
October	6.7	6.7	1.5	8.4	6.1	3.1	5.4	6.4
November	-0.8	3.6	2.7	-4.2	-0.9	-0.1	0.1	-1.4
December	-5.9	-10.1	-11.4	-5.1	-1.3	-6.2	-6.7	-5.6
Annual (Jan to Dec)	5.9	5.1	4.2	5.0	4.4	5.5	5.0	5.0
Growing season (May to Sep)	14.4	13.6	13.3	11.7	13.6	14.0	13.4	13.4

Table 3.2. Total precipitation from 2007 to 2012 and 30-yr (1971 to 2000) average values for the Pincher Creek AUT weather station (ARD 2013b).

Time period	2007	2008	2009	2010	2011	2012	2007-2012 average	30-yr average
	(mm)							
January	1.0	32.0	16.0	23.5	46.5	10.2	21.5	27.1
February	22.5	25.0	30.5	15.5	30.5	22.9	24.5	26.8
March	17.0	26.0	49.5	13.5	28.0	29.4	27.2	30.1
April	33.5	30.0	70.5	91.1	83.0	20.3	54.7	41.6
May	69.6	204.0	28.5	124.4	121.5	44.2	98.7	76.2
June	63.0	80.5	81.5	150.5	78.0	148.7	100.4	71.4
July	2.5	68.0	133.5	74.5	31.0	41.1	58.4	56.0
August	5.0	20.5	52.0	104.5	22.4	47.2	41.9	51.2
September	78.6	73.5	10.0	73.0	13.4	12.7	43.5	51.4
October	17.0	7.5	47.0	6.5	93.6	46.6	36.4	26.9
November	17.5	15.5	18.0	47.0	6.8	15.0	20.0	29.0
December	12.0	60.5	23.5	17.0	9.6	3.2	21.0	27.2
Annual (Jan to Dec)	339.2	643.0	560.5	741.0	564.3	441.5	548.3	514.8
Growing season (May to Sep)	218.7	446.5	305.5	526.9	266.3	293.9	343.0	306.2

The watershed was prone to particularly large (>50 mm) rain events throughout the spring and summer months (Figure 3.5). There were particularly large rain events at the end of April, end of May, and in mid-June in 2010. Other major precipitation events of note included 180 mm in 3 d near the end of May 2008; 83 mm on July 13, 2009; 106 mm in late May 2011; 72 mm in early June 2011; and 91 mm in early October 2011. The greatest above-average precipitation for a single month was in October 2011, which experienced 328% above average precipitation levels, most of which fell in a 3-d period.

Average annual total precipitation from 2009 to 2011 was similar among the four weather stations installed in the watershed, with a range of only 50 mm (Figure 3.6). The weather stations were not operational in 2007 and data were collect for only a portion of 2008 and 2012. Generally, precipitation increased with elevation, though IWS2 had slightly more precipitation than IWS3.

The precipitation recorded at the watershed stations was similar to the values reported for the Pincher Creek weather station. Annual total precipitation at the four weather stations in the watershed tended to be slightly less than the amount reported for the Environment Canada Pincher Creek AUT station (Figure 3.7). This slight difference could have been due to equipment used and natural variability. The difference was greatest in 2010 when on average about 8% less precipitation was recorded at the watershed weather stations compared to the Pincher Creek weather station. The difference in 2011 was less than 1%. Therefore, depending on the data requirements, a nearby existing weather station, i.e., within a few kilometres to a watershed, would likely provide adequate weather data for most study purposes.

The duration of the pre- and post-BMP periods varied among the BMP sites (Section 2, Figure 2.2). However, 2007 to 2009 was considered predominately the pre-BMP period and 2010 to 2012 predominately the post-BMP period. The average annual temperature for both these periods did not differ (5.1°C and 5.0°C, for pre- and post-BMP, respectively) from the 30-yr average (5.0°C) (Table 3.1). In terms of total precipitation, the pre-BMP period was similar to the 30-yr average (514.2 mm and 514.8 mm, respectively, Table 3.2). However, the average annual total precipitation in the post-BMP period (582.3 mm) was greater than the 30-yr average and the pre-BMP period.

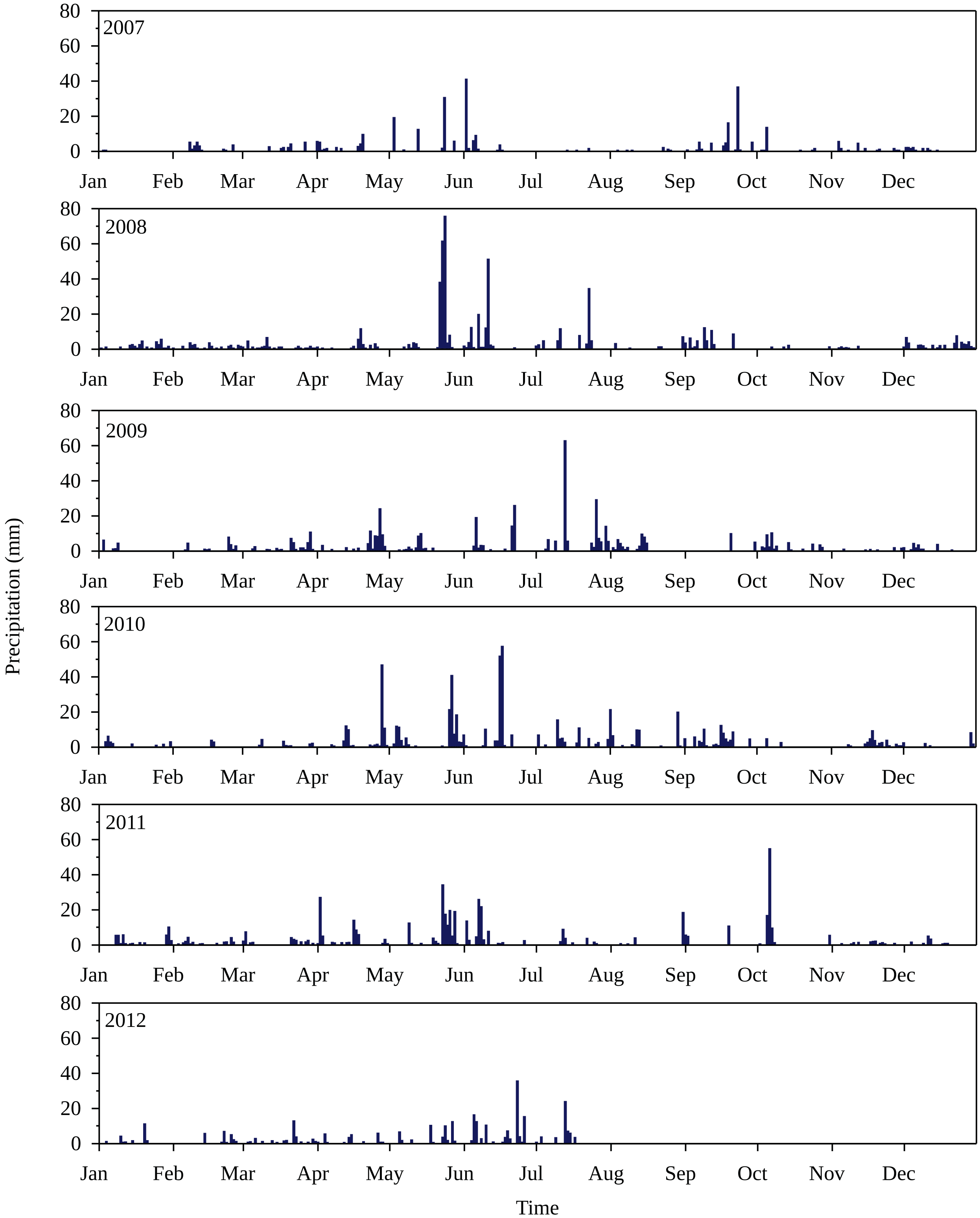

Figure 3.5 Total daily precipitation at the Pincher Creek AUT weather station from 2007 to 2012.

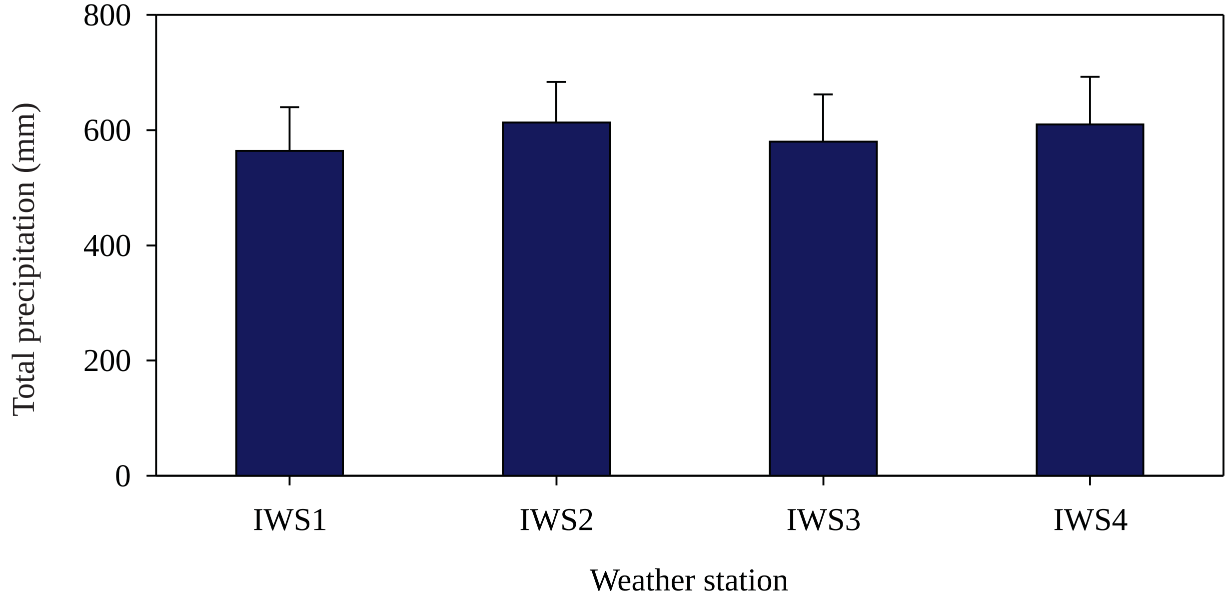

Figure 3.6. Average annual total precipitation for the four Indianfarm Creek weather stations (IWS) from 2009 to 2011 (n = 3). The stations are arranged from lowest (IWS1) to highest (IWS4) elevation. The stations were not operational in 2007 and data were collected for only a portion of 2008 and 2012. The T-bars are standard deviations.

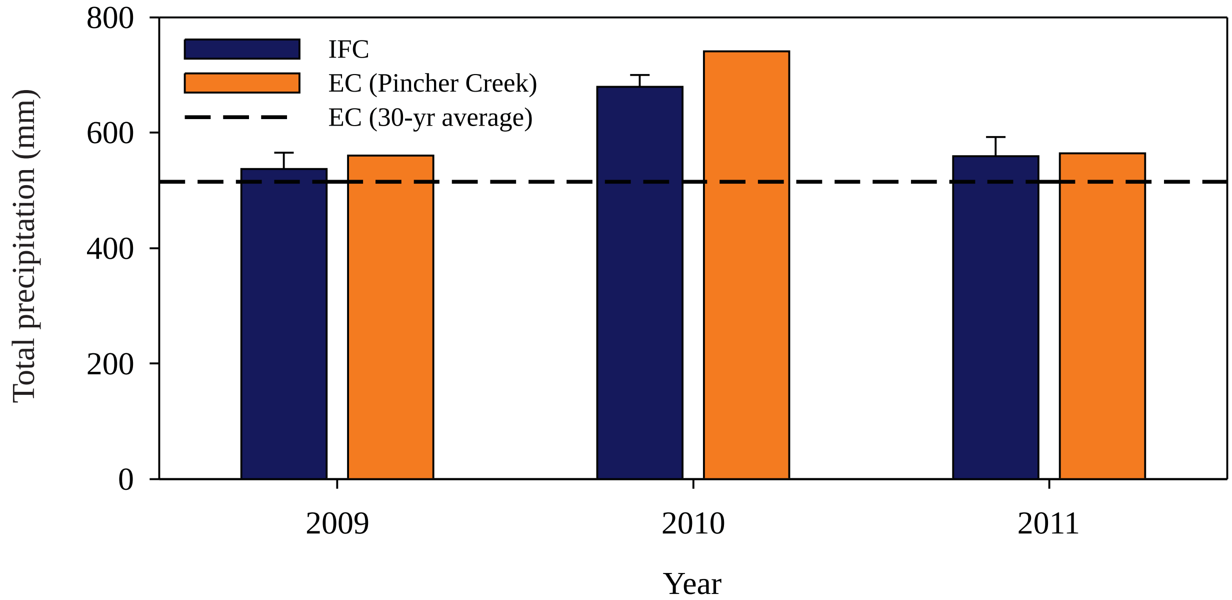

Figure 3.7. Average total precipitation of the Indianfarm Creek (IFC) weather stations (n = 4) compared to the Environment Canada (EC) Pincher Creek AUT weather station from 2009 to 2011. The stations were not operational in 2007 and data were collected for only a portion of 2008 and 2012. The T-bars for the IFC data are standard deviations.

3.3 Land Use and Land Cover

3.3.1 Methods

3.3.1.1 AgCapture Survey

From 2007 to 2012, an annual watershed-wide land use survey was completed by driving the IFC Watershed and recording land cover and land use practices using AgCapture software (Sub-section 2.5.1). Survey dates were September 24 and 25, 2007; two unknown dates in August 2008 and August 2009; September 16 and 17, 2010; August 22 and 23, 2011; and August 16 and 17, 2012. The completed AgCapture database was then processed to create maps showing the distribution of land use in the watershed. Only the 2012 maps are presented, since the distribution of land use was similar among the study years. Details about AgCapture and history of the software are reported in Sub-section 2.5.1.

3.3.1.2 Aerial Survey

On March 5, 2009, an aerial survey of the IFC Watershed was carried out. The survey consisted of a mid-to-low level, 2-h flight in a grid pattern of the entire watershed using a fixed-wing aircraft. Global Positioning System (GPS) coordinates were used to confirm the watershed boundary and additional GPS points were recorded, numbered, and labelled as points of interest within the watershed for further review and analysis, e.g., winter feeding sites. The survey was recorded using still-photography, video photography, and hand-written notes. At the time of the flight, fresh snow was on the ground surface and this was ideal to observe certain features, such as cattle wintering sites. Livestock locations were recorded and photographed to help estimate the number of cattle grazing in the watershed.

3.3.2 Results and Discussion

3.3.2.1 AgCapture

The proportion of major land uses in the watershed was similar during the study period from 2007 to 2012 (Table 3.3). Similarly, AgCapture maps for 2012 (Figures 3.8 to 3.11), showing land use distribution, were representative of the watershed for the previous study years. From 2007 to 2012, an average of approximately 97% of the IFC Watershed land base was used for agriculture-related practices. The major agricultural land uses in the IFC Watershed were distributed among annual crops (39%), perennial crops (56%), and farmyards (<2%) (Table 3.3). Other land uses included 1% natural areas (water bodies, wetlands, and grassed areas) and 3% non-agricultural areas (residential, idle land, and infrastructure). In 2008 and 2009, the land use on a small percentage (≤0.7%) of the watershed was unknown or not surveyed.

The lower region (north) and upper region (south) of IFC (Figure 3.2) were distinctively different in land-use practices. Land use in the lower region of the watershed was dominated by annual cropping (about 70% of the area) and included some livestock and one large feedlot (Figures 3.8 and 3.9). The upper region, which started in the Rocky Mountain Foothills, had a greater proportion of pasture and hay land (about 75% of the area), some annual cropping, and one medium-sized feedlot. Compared to the lower region, the upper region was more undulating

Table 3.3. Percent cover of land-use practices in the Indianfarm Creek Watershed from 2007 to 2012.

Land-use practice	2007	2008[z]	2009[z]	2010	2011	2012	Average
Barley	na[y]	39.6	32.9	29.9	22.1	16.3	28.2
Canola	na	0	0	2.5	8.8	16.1	5.5
Fallow	na	0	0	0.1	0.4	0	0.1
Oat	na	0.5	2.4	3.9	2.8	1.7	2.2
Pea	na	0	0	0.1	1.1	1.2	0.5
Soybean	na	0	0	0.1	0	0	0.02
Wheat	na	2.3	1.7	1.5	3.3	4.8	2.8
Unknown	na	0	0	0	0.02	0.02	0.01
Annual crops total	**40.0**	**42.4**	**37.0**	**38.1**	**38.5**	**40.1**	**39.3**
Hay - grass	na	4.8	1.1	1.9	1.9	1.8	2.3
Hay - legume	na	0.4	5.8	9.7	8	8.3	6.4
Hay - mixed	na	9.2	9.4	5.9	7.1	6.6	7.6
Hay total	**12.8**	**14.4**	**16.3**	**17.5**	**17**	**16.7**	**15.8**
Pasture - grass	na	27.1	3.2	4.9	4.7	4.3	8.8
Pasture - legume	na	0	2.4	0	0	0	0.5
Pasture - mixed	na	1.3	1.7	8.2	7.5	7	5.1
Pasture - native	na	4.2	28.3	21.1	23.1	22.7	19.9
Pasture - woodland	na	5.6	3.1	4.1	3.4	3.4	3.9
Pasture - riparian	na	0	0.03	2.2	1.9	1.8	1.2
Pasture total	**44.0**	**38.2**	**38.7**	**40.5**	**40.6**	**39.2**	**40.4**
Perennial crops total	**56.8**	**52.6**	**55.0**	**58.0**	**57.6**	**55.9**	**56.0**
Farmyards	na	1.3	1.6	1.4	1.4	1.4	1.4
Unknown agriculture	na	0.6	0	0	0	0	0.1
Agriculture total	**97.1**	**96.9**	**93.6**	**97.4**	**97.4**	**97.4**	**96.6**
Idle	na	0	0.05	0.01	0.01	0.01	0.02
Commercial	na	0	0.02	0.01	0.01	0.01	0.01
Industrial	na	0.06	0.01	0.01	0.01	0.01	0.02
Natural areas	na	0.84	1.84	0.73	0.72	0.72	0.97
Residential	na	0	0.18	0.01	0.01	0.01	0.04
Transportation	na	1.51	4.08	1.84	1.84	1.84	2.22
Unknown	na	0.06	0	0	0	0	0.01
Other land uses total	na	**2.5**	**6.2**	**2.6**	**2.6**	**2.6**	**3.3**
Not surveyed	na	0.7	0.2	0	0	0	0.2

[z] Percentages were updated from previous reports (Olson and Kalischuk 2011).
[y] na = not available. Less detailed data were collected in 2007.

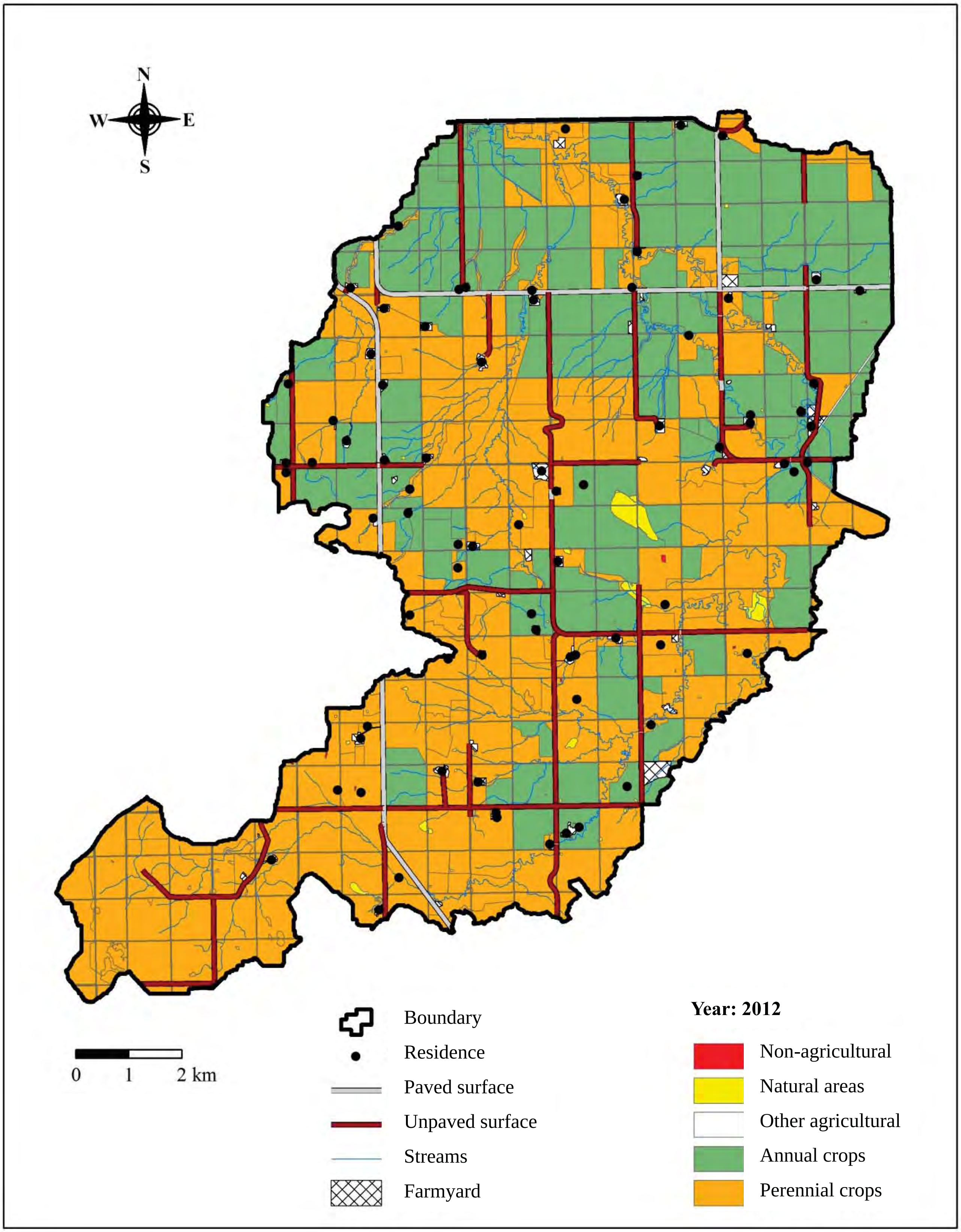

Figure 3.8. Annual and perennial crop in the Indianfarm Creek Watershed in August 2012.

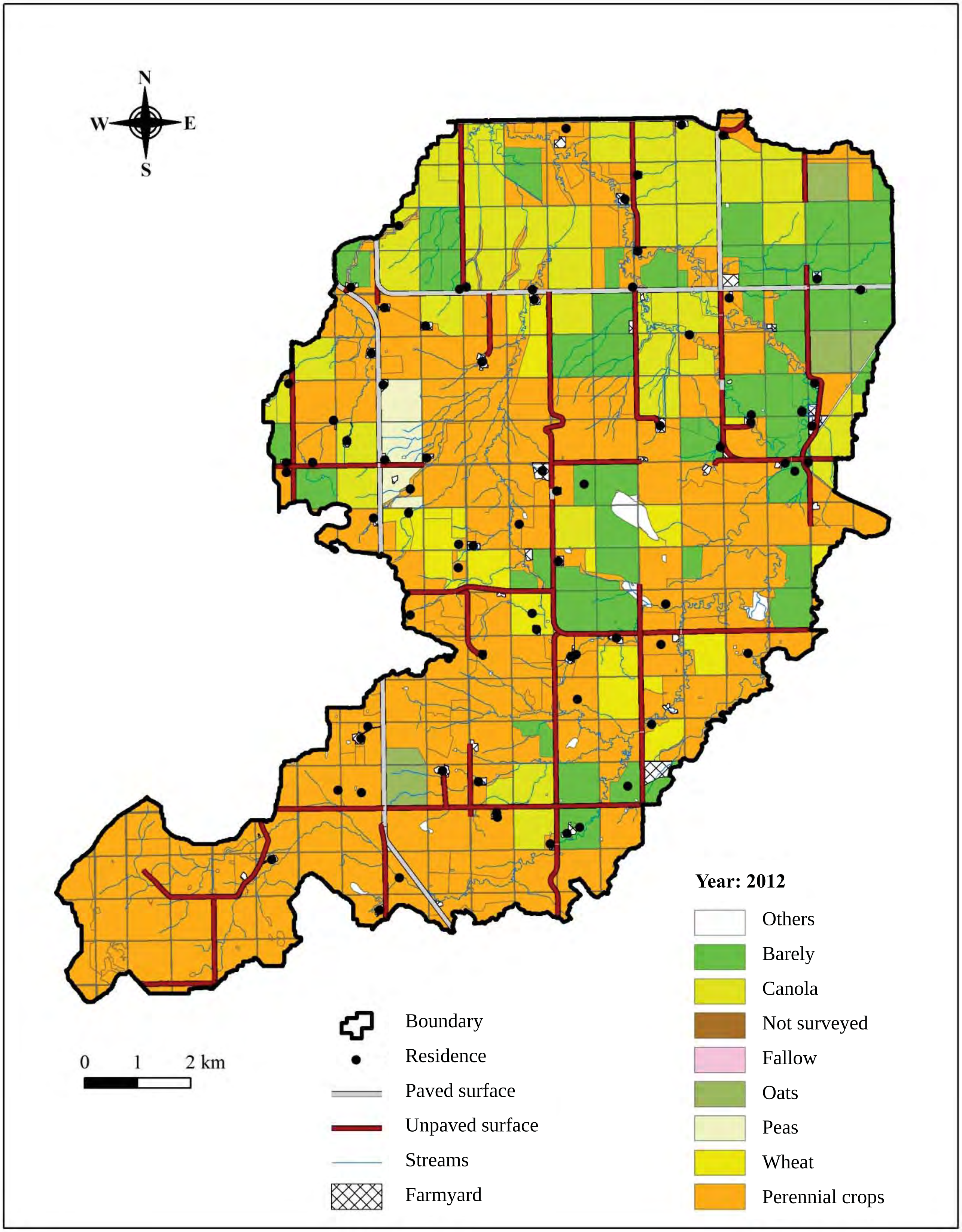

Figure 3.9. Annual crop location and types in the Indianfarm Creek Watershed in August 2012.

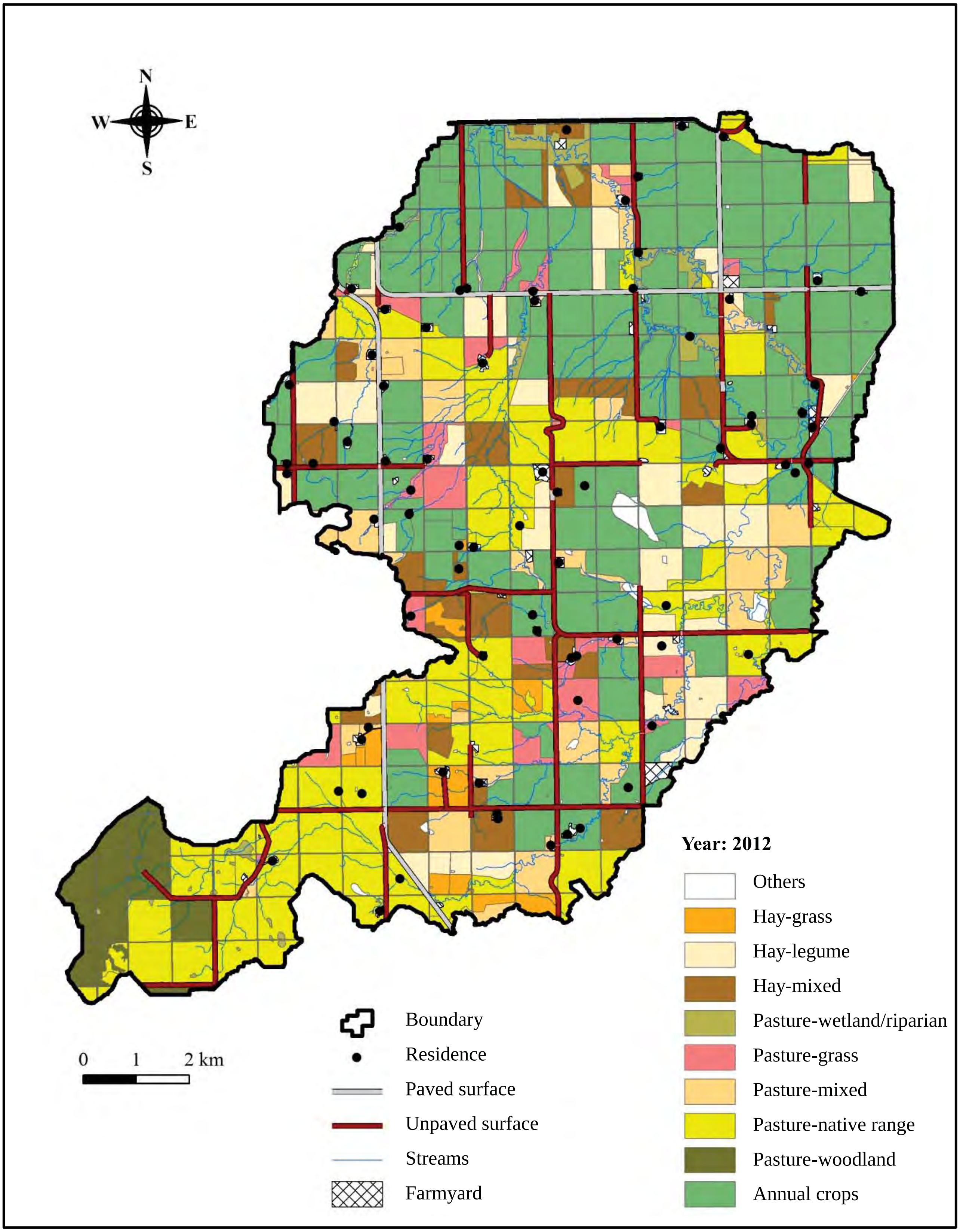

Figure 3.10. Perennial crop location and types in the Indianfarm Creek Watershed in August 2012.

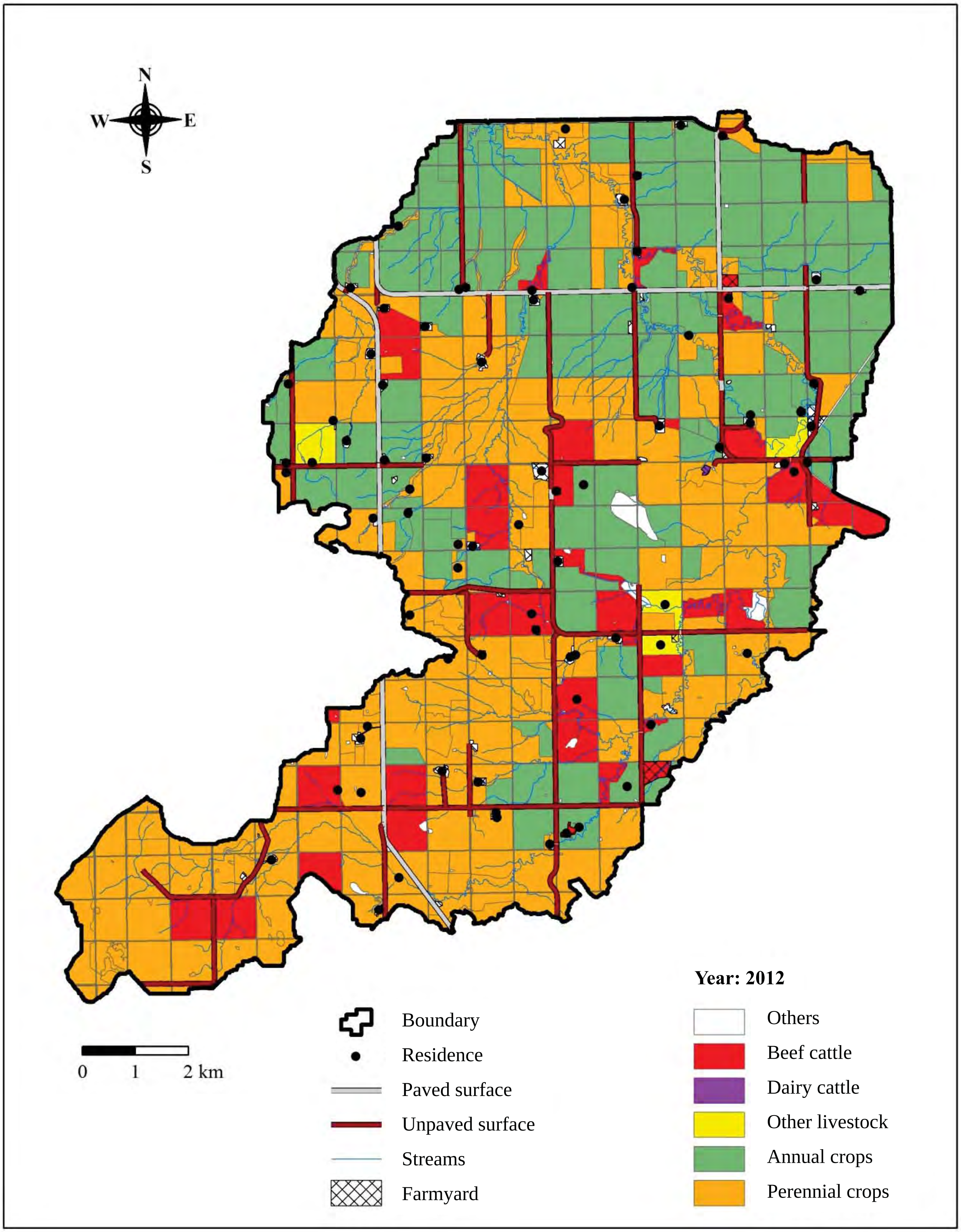

Figure 3.11. Livestock distribution in the Indianfarm Creek Watershed in August 2012.

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.

From 2008 to 2012, barley was the major annual crop at 28.2% of total land-use cover on average (Table 3.3). Other crops included canola (5.5%), wheat (2.8%), and oat (2.2%) along with some pea, soybean, and fallow to make up the rest of the annual crop land (Table 3.3, Figure 3.9). Commodity prices influenced some changes with time. There was a decrease in barley production from 40% (2008) to 16% (2012) and a subsequent increase in canola production from 0% (2008) to 16% (2012). There was also a slight increase in wheat production from 2010 (1.5%) to 2012 (4.8%), while other crop production was more stable. There was a greater variety of annual crops from 2010 to 2012 compared to 2008 and 2009. The annual crop area was slightly higher in 2008, and this was likely due to watershed boundary adjustments made in 2009.

Perennial or permanent land cover averaged 56.0% of the IFC Watershed, of which 40.4% was in pasture land and 15.8% in hay production (Table 3.3, Figure 3.10). From 2008 to 2009, there was a 24.1% increase in native range and a 23.9% decrease in pasture grass. This was due to inconsistent classification of pasture types during the surveys. Of the 40.4% pasture land, approximately half (19.9%) was in native range during the study. Of the 15.8% land used for hay production, the majority consisted of legumes (6.4%) or a legume grass mix (7.6%) (Table 3.3, Figure 3.10). The slight variations in perennial cover and subsequent variations in annual crop area were likely due to commodity prices.

The livestock distribution in 2012 (Figure 3.11) included feedlots and grazing beef cattle, dairy cattle, horses, and sheep. No results are shown for previous years because of inconsistencies in data collection, but it is expected that livestock distribution was similar to that observed in 2012. About 34,500 head of cattle were estimated to be in the watershed, including cow-calf and feedlot operations.

The AgCapture data collection and map generation provided a good representation of land use for a watershed of this size. There were some information gaps due to restricted access during the ground survey. AgCapture surveys only provide a snapshot of land cover conditions for a given time. However, annual surveys did show that major land uses remained fairly consistent in the watershed year after year. Furthermore, when changes did occur, such as the shift from barley to canola as described above, the survey technique was sensitive enough to identify this.

3.3.2.2 Aerial Survey

The aerial survey of the upper region of the watershed (Figure 3.12a,b) showed a more equal distribution among annual cropland, perennial forage, and cattle activity compared to the lower region. The lower region was defined more by annual cropping practices with most of the natural vegetation restricted to the IFC channel and tributaries (Figure 3.12c). Three feedlots were observed in the lower region (Figure 3.12d) and these feedlots likely influenced land use towards annual cropping for livestock feed.

The grazing cattle population was estimated at about 2500 animals based on the photographs taken during the survey. Stocking rate guidelines for the foothills rough-fescue region of Alberta (Adams et al. 2003) suggests that IFC Watershed could theoretically support 4900 grazing cattle. However, this estimate should be adjusted to about 2700 animals because 40% of the land base in the watershed is in crop production (Table 3.3). Therefore, the IFC Watershed, as a whole, was not overstocked at the time of the aerial survey in 2009, assuming equal distribution of cattle throughout the pasture land. Even though estimated stocking rate was within guidelines for maintaining healthy rangeland on a watershed scale, the distribution of cattle along the creek has resulted in stream bank and riparian zone degradation, particularly in the lower region. This noted degradation was based on visual observations and vegetation surveys completed at different points along the IFC channel.

The number of grazing cattle was more concentrated in the upper region of the watershed, and this was supported by the ground-based land-use surveys. Observations showed that cattle were winter fed in close proximity to feed sources or farmyards in early March (Figure 3.13). This livestock management practice was expected at this time of year, as animals are kept closer to home during calving season. Winter grazing can be used to supplement feeding.

Cattle density appeared to be lower in the lower region compared to the upper region. However, the cattle in the lower region were confined to smaller parcels of land for grazing. 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 3.14). Not all of these winter feeding sites were actively used, but they provided shelter and areas for cattle to linger. There was a significant fall stubble-grazing component to cattle management within the watershed, and this provided additional land for grazing. Cattle grazed post-harvest on annual cropland stubble to utilize re-growth, screenings, and grain straw. Chaff piles (remaining grain screenings collected into piles), green or hay feed, and portable wind fences for shelter were also noted within the IFC Watershed during winter grazing on stubble.

Figure 3.12. Images of Indianfarm Creek Watershed during the aerial survey on March 9, 2009 showing (a) the upper region, which includes mainly pasture and forage land; (b) a feedlot, rangeland, and annual cropland in the upper region; (c) the lower region with annual crop fields surrounding the tributary at the Reference BMP site; and (d) the lower region near the watershed outlet with a feedlot and the mainstem of the creek, which is surrounded by annual crop land.

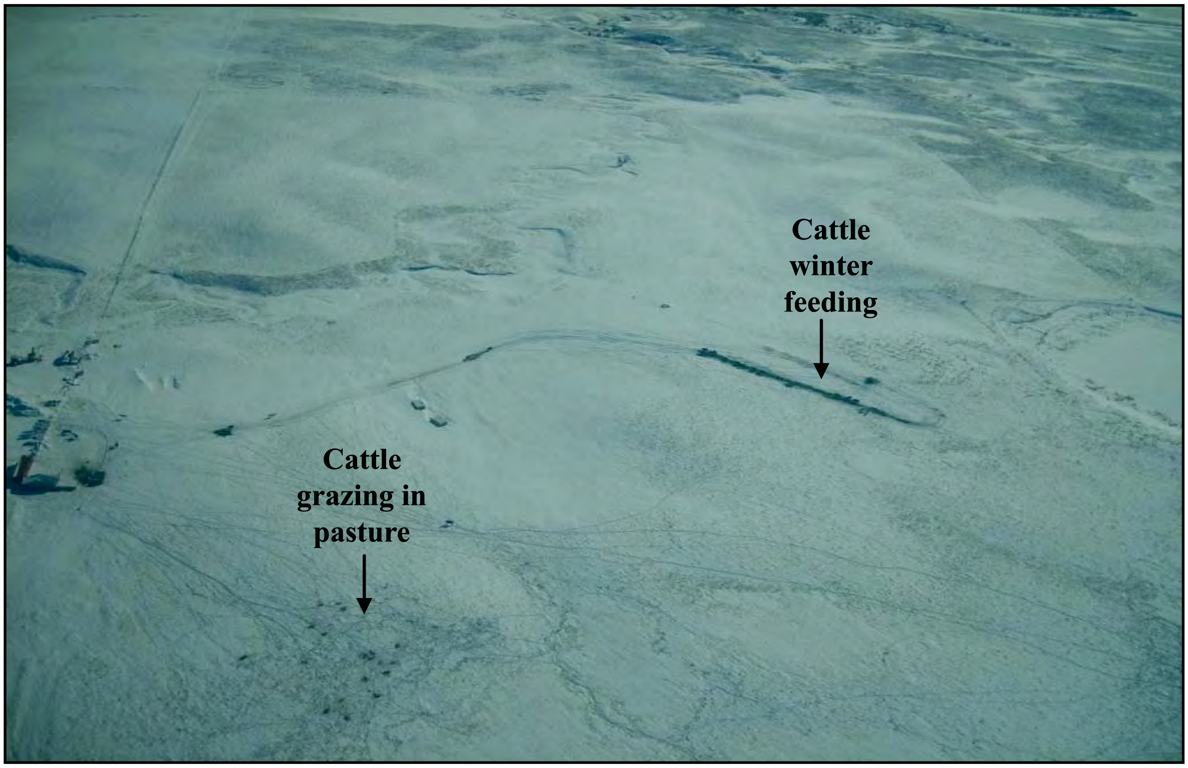

Figure 3.13. Aerial view of cattle winter feeding sites in the upper region of the watershed.

Tributaries of IFC in the lower region were often left as thin bands of grass or perennial forage surrounded by annual crops (Figure 3.14).These tributaries are areas of particular interest because of the proximity to annual crop land and the accompanying nutrient management practices used on the land. The aerial survey, along with the ground survey, showed that these tributaries generally were influenced by livestock, either through confined feeding or fall-winter grazing. The narrow grassed waterway is an obvious area for cattle to concentrate for forage and/or bedding. This can result in greater than normal manure concentrations as well as cause riparian degradation. The increased manure load and degradation of riparian zones can affect nutrient concentrations in spring snowmelt and rainfall runoff within the contributing areas.

The purpose of the aerial survey was to evaluate and assess different aspects of the watershed and to verify the AgCapture surveys. Because of the large area of the IFC Watershed and uneven topography and elevation, the aerial survey provided the means to observe several areas of interest within the watershed that could not be readily viewed or evaluated on the ground.

Figure 3.14. Aerial view of the Indianfarm Creek mainstem with a narrow band of limited natural forage, which is surrounded by annual cropland.

3.4 Watershed Hydrology and Water Quality

For 6-yr (2007 to 2012), watershed-wide stations in IFC Watershed were sampled during snowmelt, rainfall, and base-flow events. Data from these events allowed for the characterization of overall water quality and quantity and assessment of how water quality changed from the headwaters to the outlet of IFC. In addition, two synoptic surveys were carried in May 2008: one at low flow and one at high flow. A synoptic survey is the technique of tracking and sampling a single parcel of water as it moves downstream. Synoptic surveys were completed at 17 sites along the mainstem and at seven tributary sites. The objectives of the IFC watershed-wide assessments and synoptic surveys were to:

- Characterize the watershed in terms of hydrology and water quality during snowmelt, rainfall, and base flow;
- Determine tributary flow and water quality contributions to the outlet;
- Track a parcel of water to assess changes in water quality (synoptic survey); and
- Identify areas in the watershed that may benefit most from the implementation of BMPs.

Streambed sediment samples were also collected and analyzed for soil-test P (STP) content. The P sorption index (PSI) and the degree of phosphorus saturation (DPS) were also determined and compared to total dissolved P (TDP) concentration in water samples collected during the synoptic surveys. The purpose of this comparison was to determine if there was a relationship between TDP in water and DPS of sediment samples.

3.4.1 Methods

3.4.1.1 Watershed-wide Assessment

Nine watershed-wide stations (Stations 1, 2, 5, 12, 13, 14, 16, 19, and 20) were established on the mainstem and major tributaries of IFC in 2007. In 2009, Station 2 was replaced with Station 3, while Station 23 was added to the mainstem in 2010 (Figure 3.3). Water samples were collected by grab sampling and then analyzed in the laboratory as described in Sub-sections 2.8.2 and 2.8.3. During the study, 38 snowmelt, 54 rainfall, and 36 base-flow events were monitored throughout the watershed and at the Indianfarm Creek outlet (Station 1). Continuous flow data were collected at Stations 1, 5, and 12 from 2007 to 2012 (Sub-section 2.7). Station 2 was discontinued in 2010 and continuous flow data collection was started at Station 16 in 2010. The other stations were equipped with staff gauges.

The relationship between flow ($m^3\ s^{-1}$) and water quality parameter concentration was examined for Station 1 (IFC outlet). For grab samples, flows used were measured at the time of sampling. For Isco samples, flows used were averaged values for the periods that the Isco samples were collected.

Annual mass loads of nutrients and total suspended solids (TSS) and flow-weighted mean concentrations (FWMCs) of total nitrogen (TN) and total phosphorus (TP) were calculated for the watershed outlet (Station 1). The TN and TP loads and FWMC values were compared to the dataset from the Alberta Environmentally Sustainable Agriculture (AESA) Water Quality Project, during which the outlets of 23 watersheds were monitored from 1999 to 2006 (Lorenz et al. 2008).

A nutrient water quality sub-index (NWQS-I) was used to compare relative differences in overall water quality among years for Station 1. The sub-index was adopted from the Alberta Agricultural Water Quality Index (Wright et al. 1999) utilizing nutrient parameters. The sub-index was calculated using three factors: (1) the number of objectives that were not met, (2) the frequency with which the objectives were not met, and (3) the amount by which the objectives were not met. Seven nutrient water quality objectives were used in the NWQS-I (Table 3.4). Index scores ranged from 0 (worst quality) to 100 (best quality), and scores were grouped into five categories: poor (0-40), marginal (41-55), fair (56-70), good (71-85), and excellent (86-100).

3.4.1.2 Synoptic Survey

Two synoptic surveys were carried out in May 2008: a low-flow synoptic survey and a high-flow synoptic survey. The low-flow synoptic survey was carried out from May 12 to 16, and was 1 mo following the snowmelt period. With little precipitation and no snowmelt in early May, the data from this survey were considered base flow with no active runoff from the landscape. The high-flow synoptic survey was carried out during higher flow conditions from May 26 to 28, following a 3-d rainfall event (180 mm).

Sampling sites. Seventeen water-monitoring sites were used along the mainstem of IFC, as well as seven tributary sites for the synoptic surveys (Figure 3.15). These sites were identified with letters from A to X (Table 3.5). Two of these sites were existing watershed-wide stations: Stations 20(A) and 1(X). Most of the 17 mainstem sites were upstream and downstream of the seven tributary inflows. The downstream site for each tributary was chosen carefully by observing sediment dispersal to ensure an adequate mixing zone in the IFC mainstem. The exception was for Sites K and L, which were upstream and downstream of a number of acreages rather than the outlet of a tributary.

Table 3.4. Water quality objectives used in the calculation of the Nutrient Water Quality Sub-Index (NWQS-I).

Nutrient[z]	NWQS-I objectives ($mg\ L^{-1}$)[y]
TN	1.253
TKN	1.22
NH_3-N	0.038
NO_2-N + NO_3-N	0.031
NO_2-N	0.005
TP	0.15
TDP	0.064

[z] TN = total nitrogen, TKN = total Kjeldahl nitrogen, NH_3-N = ammonia nitrogen, NO_2-N = nitrite nitrogen, NO_3-N = nitrate nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus.
[y] From Wright et al. (1999).

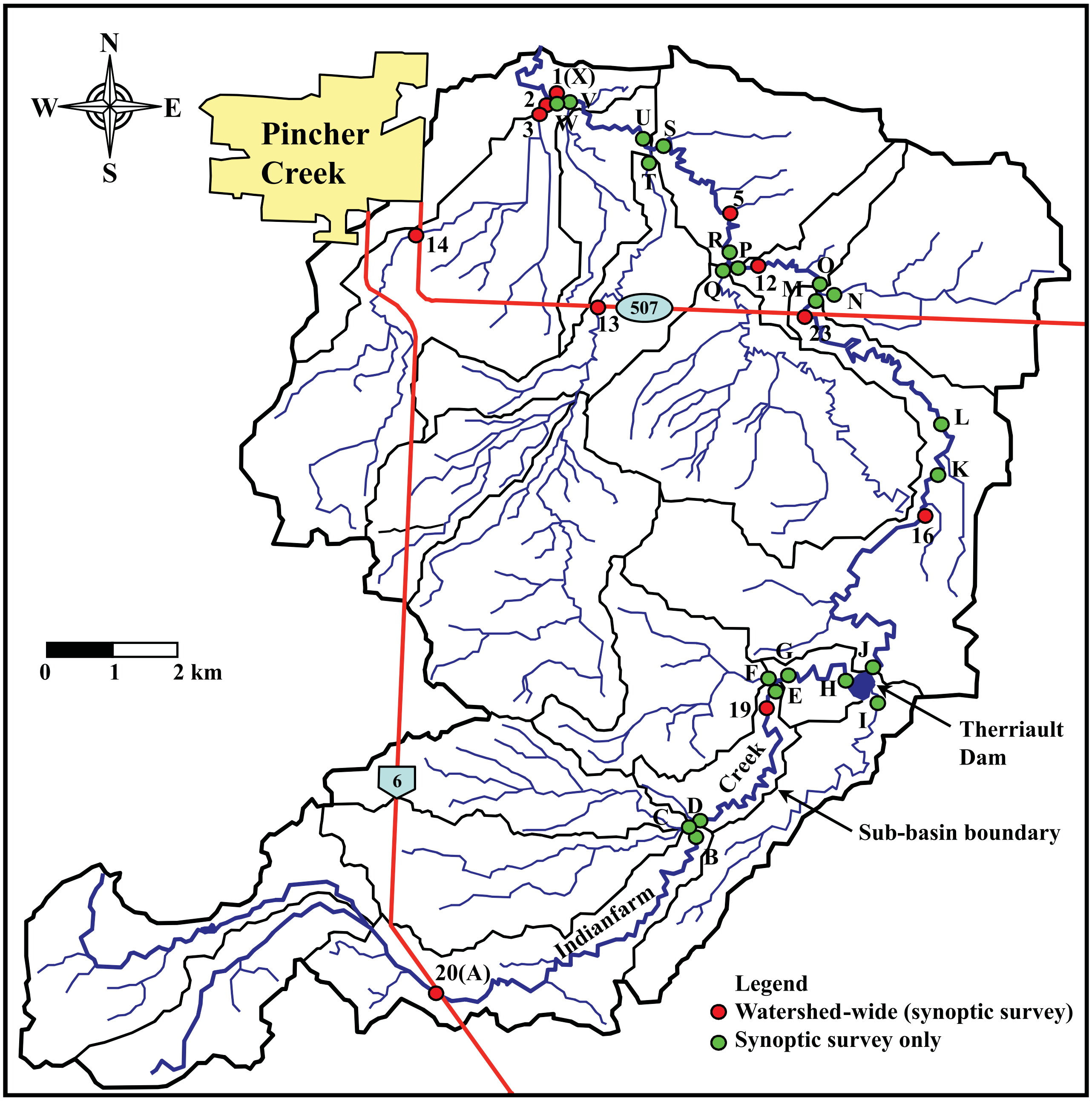

Figure 3.15. Locations of watershed-wide stations (numbers), synoptic-survey sites (letters), and sub-basins in Indianfarm Creek Watershed.

Table 3.5. List of synoptic-survey sites used in Indianfarm Creek in 2008.			
Mainstem sites (km)[z]			Tributary sites
A (0)[y]	J (21.496)	R (39.446)	C
B (10.459)	K (27.853)	S (45.961)	F
D (10.555)	L (30.273)	U (46.001)	I
E (16.681)	M (35.906)	V (48.463)	N
G (16.757)	O (35.946)	X (48.663)[y]	Q
H (20.146)	P (39.083)		T
			W[x]

[z] Distance downstream along the mainstem of Indianfarm Creek shown in parenthesis starting at the furthest upstream site (A).
[y] Indicates those sites that overlap with the watershed-wide stations.
[x] Site W was a tributary that consisted of pooled or very slow moving water and was sampled at four points: W, W1, W2, and W3, which transect east to west across the pooled water. Results from these four points were averaged to obtain a more representative value for Site W.

Travel-time estimates. Water travel times were estimated to track and sample a parcel of water from the headwaters to the outlet of the mainstem. Travel times in the creek were estimated using the Soil and Water Assessment Tool (SWAT, version 6.3.10). The SWAT model required the input of four characteristics at each sampling location: channel length, channel slope, cover factor, and an N-value. Channel lengths and slopes were estimated using 2-m grid digital elevation model data, while the cover factor was determined by field observations. The N-values were calculated using the following equation:

$$\text{N-value} = \text{Manning n } (0.08) \times \text{cover factor} \quad (3.1)$$

Travel velocity (V) was then calculated using SWAT and the following equation:

$$V = 0.489 \times Q^{0.25} \times \text{Slope}^{0.375} \div N^{0.75} \quad (3.2)$$

where: V = travel velocity ($m\ s^{-1}$)
Q = flow ($m^3\ s^{-1}$)
Slope = channel slope ($m\ m^{-1}$)
N = N-value (unitless)

Travel time of a water parcel was then estimated using the following equation:

$$T = L \div (V \times 60) \quad (3.3)$$

where: T = travel time (min)
L = channel length (m)
V = travel velocity ($m\ s^{-1}$)

It is important to note that travel velocity estimates were not based on a calibrated model.

Synoptic survey procedures. Therriault Dam was between the headwaters and the outlet of the watershed (Figure 3.15), and for simplification, the synoptic surveys were completed in two sections. The first section was from Sites A to H (including tributary Site I) and the second section was from Sites J to X.

Following the travel-time schedule, one water grab sample was taken at each site. The procedure involved filling two, 1-L bottles consecutively and these samples were analyzed for a suite of nutrients including P and N parameters, TSS, and *Escherichia coli* (*E. coli*) (Sub-section 2.8.3). During the low-flow survey, four sites (Sites F, J, N, and Q) could not be sampled because of no flow, and during the high-flow survey, one site (Site Q) could not be sampled for the same reason.

As part of the QA/QC for the synoptic surveys, duplicate samples were taken from randomly chosen sites during both surveys. Duplicate samples were collected at Sites H and K during the low-flow survey and at Site W during the high-flow survey.

After each site was grab sampled, flow metering was carried out. Flow metering was done using a FlowTracker Acoustic Doppler Velocity (FlowTracker) meter (Son Tek/YSI, San Diego, California) or a StreamPro (Teledyne RD Instruments, Poway, California) for the low-flow survey (Sub-section 2.7.5; Table 3.6). Overall, flow during the low-flow synoptic survey was very low and difficult to determine. Some values were adjusted using upstream and downstream flows. If an upstream and downstream evaluation was irrelevant (i.e., negligible or no flow from tributaries), the site was given a flow value of 0.0001 m^3 s^{-1} to allow for further calculations. Few problems were encountered during the high-flow survey and flow metering was carried out using a FlowTracker, a Swoffer current velocity meter (model 3000; Swoffer Instruments Inc., Seattle, Washington), or a StreamPro (Table 3.7). The flow values measured at mainstem Sites J to X during the high-flow survey were larger than normal with water releases from Therriault Dam.

Table 3.6. Water sampling and flow-metering summary for the low-flow synoptic survey from May 12 to 16, 2008.

Site	Sampling time	Flow-metering time	Flow-metering method
A	5/12/08 3:00 PM	5/12/08 3:20 PM	FlowTracker
B	5/13/08 7:10 AM	5/13/08 7:24 AM	FlowTracker
C	5/13/08 7:10 AM	5/13/08 7:24 AM	FlowTracker
D	5/13/08 7:18 AM	5/13/08 7:44 AM	FlowTracker
E	5/13/08 3:16 PM	5/13/08 3:49 PM	FlowTracker
F	No flow		
G	5/13/08 3:39 PM	5/13/08 3:49 PM	FlowTracker
H	5/13/08 8:42 PM	5/13/08 8:32 PM	FlowTracker
I	5/13/08 4:43 PM	Estimated[z]	
J	No flow		
K	5/14/08 7:30 PM	5/14/08 7:40 PM	FlowTracker
L	5/14/08 10:49 PM	5/14/08 9:00 PM	FlowTracker
M	5/15/08 8:19 AM	5/15/08 8:42 AM	FlowTracker
N	No flow		
O	5/15/08 8:32 AM	5/15/08 8:42 AM	FlowTracker
P	5/15/08 12:28 PM	5/15/08 1:04 PM	FlowTracker
Q	No flow		
R	5/15/08 12:54 PM	Estimated[y]	
S	5/15/08 8:36 PM	5/15/08 8:53 PM	FlowTracker
T	5/15/08 8:36 PM	5/15/08 8:53 PM	FlowTracker
U	5/15/08 8:43 PM	5/15/08 9:13 PM	FlowTracker
V	5/16/08 6:23 AM	Estimated[x]	
W	5/16/08 6:23 AM	5/16/08 7:03 AM	FlowTracker
X	5/16/08 6:30 AM	5/16/08 6:30 AM	FlowTracker

[z] The flow was too low to flow meter using the FlowTracker. The lowest flow value of 0.0001 $m^3 s^{-1}$ was assigned to this tributary to allow for calculations of export coefficients.

[y] Flow values were adjusted as the FlowTracker was unable to achieve a realistic flow value. Flow was assumed to be the same as Site P given that Tributary Q had no flow.

[x] Flow values were adjusted as the StreamPro was unable to achieve a realistic flow val ue. The flow was determined by subtracting the outlet flow (Site X) from Tributary W flow.

Table 3.7. Water sampling and flow -metering summary for the high-flow synoptic survey from May 26 to 27, 2008.

Site	Sampling time	Flow-metering time	Flow metering-method
A	5/26/08 8:25 AM	5/26/08 8:45 AM	StreamPro
B	5/26/08 2:11 PM	5/26/08 3:00 PM	FlowTracker
C	5/26/08 2:11 PM	5/26/08 3:30 PM	FlowTracker
D	5/26/08 2:15 PM	5/26/08 3:43 PM	StreamPro
E	5/26/08 6:25 PM	5/26/08 7:10 PM	StreamPro
F	5/26/08 6:25 PM	5/26/08 7:13 PM	FlowTracker
G	5/26/08 6:32 PM	5/26/08 7:25 PM	StreamPro
H	5/26/08 7:52 PM	5/26/08 8:18 PM	StreamPro
I	5/26/08 4:25 PM	5/26/08 4:30 PM	FlowTracker
J	5/26/08 9:00 PM	5/26/08 10:15 PM	FlowTracker
K	5/27/08 1:30 AM	5/27/08 2:30 PM	Swoffer
L	5/27/08 3:00 AM	5/27/08 3:30 PM	Swoffer
M	5/27/08 8:10 AM	5/27/08 11:43 AM	StreamPro
N	5/27/08 8:15 AM	5/27/08 8:56 AM	FlowTracker
O	5/27/08 8:25 AM	5/27/08 11:15 AM	StreamPro
P	5/27/08 10:35 AM	5/27/08 5:14 PM	StreamPro
Q	No flow		
R	5/27/08 10:40 AM	Estimated[z]	
S	5/27/08 3:17 PM	5/27/08 9:51 PM	StreamPro
T	5/27/08 3:17 PM	5/27/08 9:27 PM	StreamPro
U	5/27/08 3:18 PM	5/27/08 9:36 PM	StreamPro
V	5/27/08 6:49 PM	Estimated[x]	
W	5/27/08 6:29 PM	5/27/08 7:05 PM	FlowTracker
X	5/27/08 7:03 PM	5/27/08 6:30 PM	FlowTracker

[z] Flow values were assumed to be the same as Site P since Tributary Q had no flow.
[y] Flow was estimated as it became too dark to flow meter with the FlowTracker. Flow was determined by subtracting Site W from Site X.

3.4.1.3 Streambed Sediment Sampling

Streambed sediment samples were collected from 17 of the watershed-wide and synoptic survey sites on September 25 and 26, 2008. Sediment samples were not taken at Sites H, M, P, Q, R, V, and X because the streambed was under water. In addition, sediment samples were collected at water monitoring Stations 5, 8, 10, 12, 13, 14, 18, and 21 (Figure 3.3), for a total of 25 sample sites. Sediment samples were collected perpendicular to the flow of the stream channel using a Dutch auger. For channel widths less than 3 m, three samples were collected: one at each channel edge and one sample at the mid-point. For channel widths greater than 3 m, five samples were taken, one at each channel edge, one at the mid-point, and one midway between each edge and the mid-point. Channel width at sampling sites ranged from 0.8 to 5.8 m. All samples at each site were combined, mixed into a composite sample, and a sub-sample (1 kg) was removed for analysis. Samples were air dried and analyzed for STP (Qian et al. 1991) and P sorption index (Bache and Williams 1971). The degree of P sorption was calculated using the following formula (Casson et al. 2006):

$$DPS = [STP \div (STP + PSI)] \times 100 \quad (3.4)$$

Where: DPS = degree of phosphorus sorption (%)
STP = soil-test phosphorus (mg kg^{-1})
PSI = Phosphorus sorption index (mg kg^{-1})

3.4.2 Results and Discussion

3.4.2.1 Watershed Outlet (Station 1)

Watershed outlet flow. Most of the flow at the watershed outlet (Station 1) occurred from March to July each year (Figure 3.16). Generally, IFC stopped flowing during the latter part of the year. The two largest annual flows were in 2010 and 2011 (averaged 23×10^6 m^3 yr^{-1}), and the two smallest annual flows were in 2007 and 2012 (averaged 0.56×10^6 m^3 yr^{-1}) (Table 3.8). Intermediate annual flows were observed in 2008 and 2009 (averaged 5.3×10^6 m^3 yr^{-1}) compared to the other 4 yr. The largest annual flow, which was in 2010, was nearly 79-fold greater compared to the smallest annual flow observed in 2012. The greatest amount of rainfall/base flow runoff occurred in 2010 (22.9 million m^3) and 2011 (13.2 million m^3) and the greatest amount of snowmelt runoff (10 million m^3) occurred in 2011 (Figure 3.16 and Table 3.8). Notable high peak flows occurred on June 12, 2008 (13 m^3 s^{-1}), May 28, 2010 (14 m^3 s^{-1}), June 17, 2010 (80 m^3 s^{-1}), May 28, 2011 (21 m^3 s^{-1}), and June 8, 2011 (16 m^3 s^{-1}) (Figure 3.16). These high peak flows were all associated with major rainfall events (Sub-section 3.2.2).

The wide range in annual flows among the 6 yr was largely driven by the amount of total precipitation. Total precipitation was the highest in 2010; whereas, the two driest years were 2007 and 2012, which had the lowest annual flows (Table 3.8). Even though annual flow in 2011 was similar to 2010, total precipitation was 25% less in 2011 compared to 2010, and was 12% less than in 2008 and similar to 2009, and these two latter years had much smaller annual flows than in 2011. Perhaps the above average precipitation in 2010, particularly in September and October, resulted in higher antecedent soil moisture in 2011, which in turn reduced infiltration and caused more runoff. There was a strong quadratic relationship ($r^2 = 0.97$) between total precipitation and annual flow when 2011 was not included in the analysis (Figure 3.17).

The portion of annual flow generated directly by snowmelt was estimated at an average of 25% during the 6-yr study (Table 3.8). The estimated contribution from snowmelt ranged from 4% in 2010 to 43% in 2011. The remaining portion of annual flow was due to rainfall events and base flow from groundwater discharge. It was difficult to quantify the relative influence between rainfall events and base flow. However, it was observed that rainfall had a larger influence than base flow on annual flow in most years during the study.

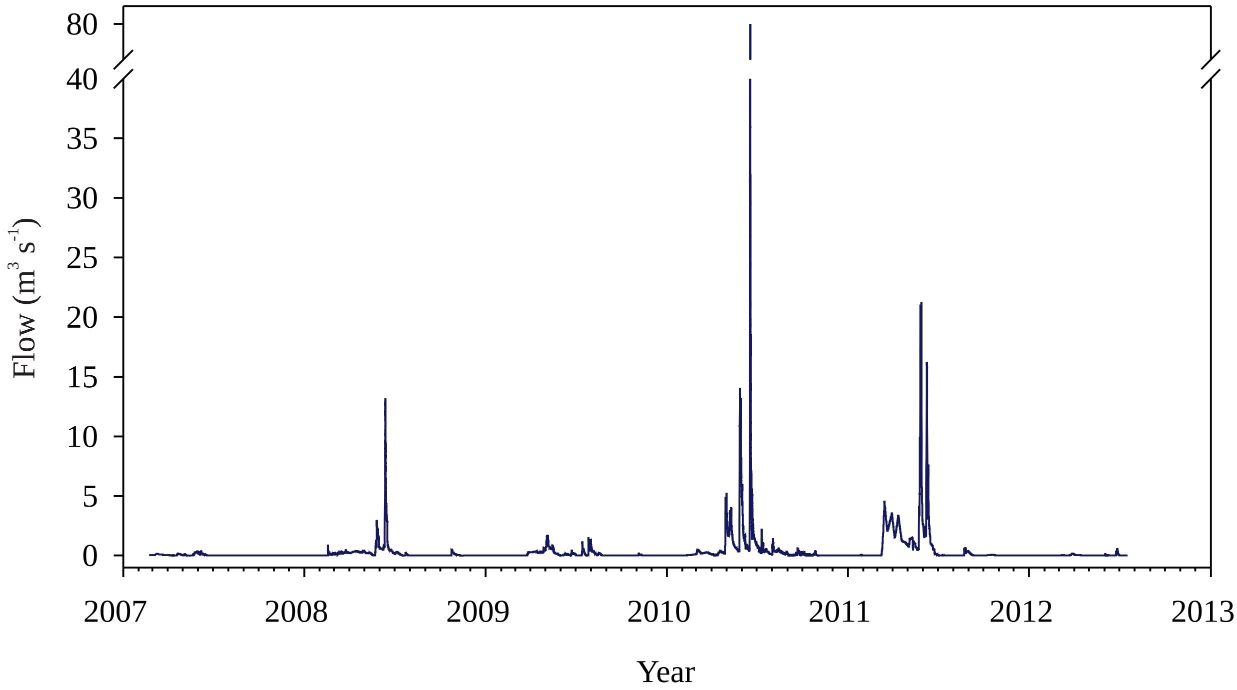

Figure 3.16. Flow measured at the Indianfarm Creek outlet (Station 1) from 2007 to 2012.

Table 3.8. 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 2013b).
[y] The 30-yr average for the Pincher Creek AUT weather station is 514.8 mm (ARD 2013b).
[x] Includes releases from Therriault Dam in 2008 and 2009.

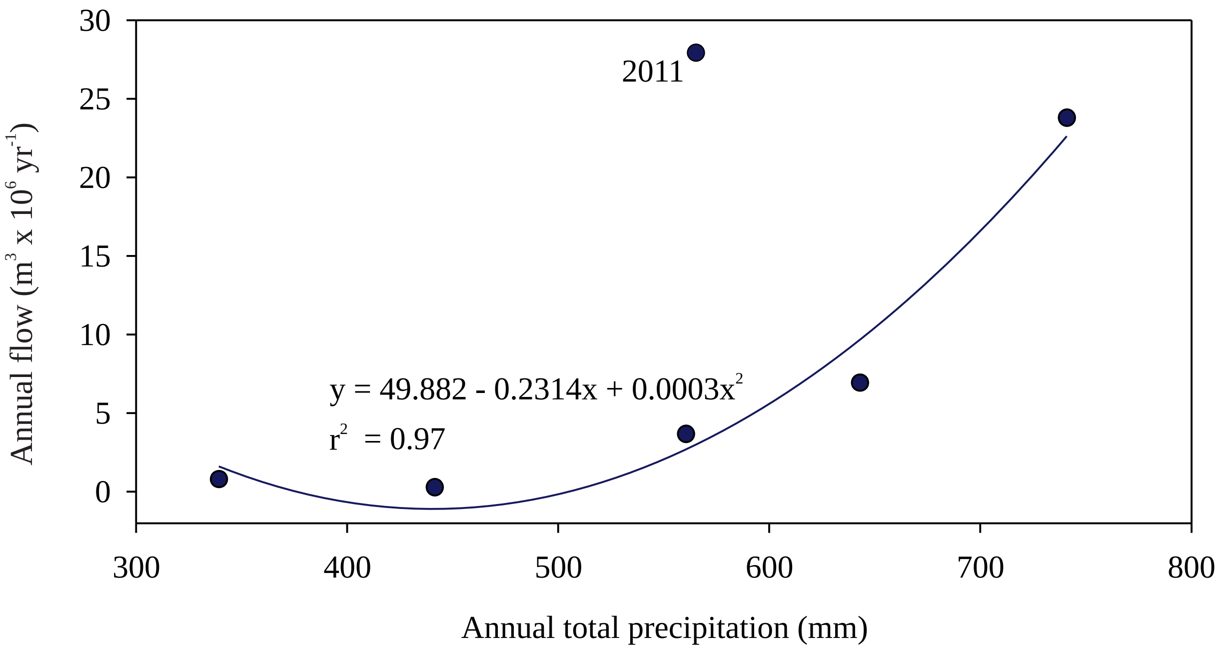

Figure 3.17. Relationship between annual total precipitation (Pincher Creek AUT weather station) and annual flow at the Indianfarm Creek outlet monitoring station (Station 1). The point for 2011 was not included in the relationship.

Watershed outlet water quality. On average for the 6 yr, the concentration of most water quality parameters, including TN, organic N (ON), nitrate nitrogen (NO_3-N), all P parameters, TSS, and *E. coli*, were highest during rainfall events at the outlet (Tables 3.9 and 3.10). For example, TN concentration during rainfall runoff was two-fold greater than during snowmelt runoff and nearly three-fold greater than during base flow. Similarly, TP concentration during rainfall runoff was 2.4-fold greater than during snowmelt runoff and nearly five-fold greater than during base flow. The differences were even larger for TSS and *E. coli*. The concentration of most parameters was lowest during base flow, except for *E. coli*, which was lowest during snowmelt. This was likely due to reduced microbial activity during the colder snowmelt period compared to later in the spring and summer months. The 6-yr average concentrations of ammonia nitrogen (NH_3-N), chloride (Cl), and electrical conductivity (EC) were highest during snowmelt at the outlet of IFC (Tables 3.9 and 3.10).

Overall, the majority of TP and TN in water samples from Station 1 was in particulate form. On average, 65% of TN was ON and 64% of TP was particulate phosphorus (PP) (Table 3.9). This was also consistent for each of the events types, though the proportion of TN in ON form was more variable than TP. Only an average of 51% TN was ON during rainfall events; whereas, 91% of TN was ON during base flow. This suggests that adopting BMPs that reduce sediment loss by reducing soil erosion and improving degraded riparian areas may have a large impact on reducing nutrient loss to the creek.

Table 3.9. Average N and P parameter concentrations at the Indianfarm Creek outlet (Station 1) from 2007 to 2012.

Year	n	TN[z]	ON	NO_3-N	NH_3-N	TP	TDP	PP
		($mg\ L^{-1}$)						
				Snowmelt				
2007	7	2.05*b*[y]	1.36*b*	0.33*b*	0.34*a*	0.18*bc*	0.06*bc*	0.12*b*
2008	15	1.27*c*	1.13*b*	0.05*c*	0.06*b*	0.09*c*	0.03*c*	0.06*b*
2009	11	1.44*bc*	1.18*b*	0.17*bc*	0.07*b*	0.15*bc*	0.05*c*	0.10*b*
2010	8	1.91*bc*	1.46*ab*	0.11*bc*	0.32*a*	0.32*b*	0.17*b*	0.15*b*
2011	8	3.08*a*	1.88*a*	0.83*a*	0.33*a*	0.75*a*	0.38*a*	0.37*a*
2012	5	1.76*bc*	1.46*ab*	0.25*bc*	0.06*b*	0.24*bc*	0.09*bc*	0.15*b*
All	*54*	*1.82*	*1.36*	*0.25*	*0.18*	*0.26*	*0.12*	*0.14*
				Rainfall				
2007	4	1.76*ab*	1.53*b*	0.11*b*	0.10*ab*	0.21*b*	0.09*b*	0.13*bc*
2008	3	4.49*ab*	3.93*a*	0.36*ab*	0.17*ab*	0.95*ab*	0.12*ab*	0.84*a*
2009	7	1.62*b*	1.48*b*	0.09*b*	0.03*b*	0.21*b*	0.09*b*	0.12*c*
2010	12	4.00*ab*	1.76*b*	2.05*ab*	0.15*ab*	0.89*a*	0.30*a*	0.59*ab*
2011	10	5.29*a*	1.83*b*	3.11*a*	0.31*a*	0.71*ab*	0.24*ab*	0.47*abc*
2012	2	3.21*ab*	1.44*b*	1.46*ab*	0.28*ab*	0.34*ab*	0.17*ab*	0.17*abc*
All	*38*	*3.66*	*1.86*	*1.60*	*0.17*	*0.62*	*0.20*	*0.42*
				Base flow[x]				
2007	4	0.95*b*	0.88*b*	0.03*a*	0.03*b*	0.06*b*	0.01*a*	0.05*b*
2008	6	1.39*ab*	1.29*ab*	0.05*a*	0.03*b*	0.13*ab*	0.03*a*	0.10*a*
2009	9	1.05*b*	0.97*ab*	0.03*a*	0.03*b*	0.07*b*	0.02*a*	0.05*b*
2010	11	1.19*ac*	1.05*ab*	0.08*a*	0.03*b*	0.16*a*	0.05*a*	0.11*a*
2011	4	1.71*a*	1.47*a*	0.10*a*	0.15*a*	0.18*a*	0.09*a*	0.08*a*
2012	2	1.59*ab*	1.56*ab*	0.03*a*	0.03*b*	0.14*ab*	0.02*a*	0.12*a*
All	*36*	*1.24*	*1.13*	*0.06a*	*0.04*	*0.12*	*0.04*	*0.08*
				Overall				
2007	15	1.68*bc*	1.28*b*	0.19*bc*	0.19*ab*	0.16*c*	0.05*c*	0.10*c*
2008	24	1.71*bc*	1.52*ab*	0.09*c*	0.07*bc*	0.21*c*	0.04*c*	0.17*bc*
2009	27	1.36*c*	1.19*b*	0.10*c*	0.05*c*	0.14*c*	0.05*c*	0.09*c*
2010	31	2.46*b*	1.43*ab*	0.85*b*	0.15*b*	0.48*ab*	0.18*b*	0.31*ab*
2011	22	3.83*a*	1.78*a*	1.73*a*	0.29*a*	0.63*a*	0.26*a*	0.36*a*
2012	9	2.05*bc*	1.48*ab*	0.47*bc*	0.10*bc*	0.24*bc*	0.09*bc*	0.14*abc*
All	*128*	*2.20*	*1.44*	*0.60*	*0.14*	*0.33*	*0.12*	*0.21*

[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.

[y] Averages among years per parameter and event type flowed by the same letter are not significantly different ($P < 0.1$).

[x] Base flow events included Therriault Dam releases that occurred on October 24, 2008 and November 5, 2009.

Table 3.10. Average total suspended solids (TSS), chloride (Cl), *Escherichia coli* (*E. coli*), electrical conductivity (EC), and pH concentrations at the Indianfarm Creek outlet (Station 1) from 2007 to 2012.

Year	n	TSS[z] (mg L^{-1})	Cl[y] (mg L^{-1})	*E. coli* (mpn 100 mL^{-1})	EC (µS cm^{-1})	pH
			Snowmelt			
2007	7	75*b*[x]	na[w]	26*ab*	894*a*	8.16*cd*
2008	15	24*b*	na	5*b*	976*a*	8.34*ab*
2009	11	61*b*	8.01*b*	112*a*	621*b*	8.42*a*
2010	8	47*b*	10.5*ab*	5*ab*	655*b*	8.23*bc*
2011	8	266*a*	11.0*a*	69*ab*	523*b*	8.03*d*
2012	5	59*b*	11.9*a*	52*ab*	838*a*	8.23*abcd*
All	*54*	*81*	*9.97*	*44*	*766*	*8.26*
			Rainfall			
2007	4	65*bc*	na	1,083*a*	832*a*	8.30*ab*
2008	3	1124*a*	na	4,100*a*	468*c*	8.13*b*
2009	7	75*c*	8.62*b*	10,654*a*	643*b*	8.38*a*
2010	12	474*b*	7.84*b*	2,528*a*	562*bc*	8.34*a*
2011	10	384*bc*	8.33*b*	2,502*a*	565*bc*	8.18*b*
2012	2	53*bc*	15.3*a*	264*a*	970*a*	8.20*ab*
All	*38*	*363*	*8.65*	*3,871*	*621*	*8.28*
			Base flow[v]			
2007	4	23*b*	na	14*b*	875*b*	8.48*a*
2008	6	39*ab*	17.3	146*b*	650*cd*	8.35*a*
2009	9	28*b*	5.99*c*	206*b*	537*d*	8.51*a*
2010	11	48*a*	9.45*b*	48*b*	713*c*	8.45*a*
2011	4	28*b*	13.0*a*	2,537*a*	876*b*	8.36*a*
2012	2	37*ab*	18.2*a*	1*b*	1105*a*	8.28*a*
All	*36*	*36*	*9.77*	*374*	*716*	*8.43*
			Overall			
2007	15	58*bc*	na	305*a*	873*a*	8.28*b*
2008	24	165*abc*	17.3	630*a*	831*a*	8.32*b*
2009	27	54*c*	7.50*c*	2,983*a*	599*b*	8.44*a*
2010	31	212*ab*	9.10*b*	997*a*	639*b*	8.35*b*
2011	22	277*a*	10.1*b*	1,624*a*	608*b*	8.16*c*
2012	9	53*bc*	14.0*a*	88*a*	927*a*	8.24*bc*
All	*128*	*152*	*9.46*	*1313*	*710*	*8.31*

[z] TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Chloride was added in late July 2008. Only one sample (n = 1) was analyzed for Cl in 2008, and therefore, not included in the statistical analysis.
[x] Averages among years per parameter and event type followed by the same letter are not significantly different (*P* <0.1).
[w] na = not available.
[v] Base flow events included Therriault Dam releases that occurred on October 24, 2008 and November 5, 2009.

The average concentrations of TN, NO_3-N, TP, TDP, PP, and TSS during snowmelt were significantly higher in 2011 (Tables 3.9 and 3.10) compared to the other years. As previously described, the largest snowmelt flow occurred in 2011, and this likely caused the higher concentrations for the above parameters. During rainfall events, no single year had significantly higher concentrations than the other years for most parameters, except for TSS and Cl. The average concentrations of TSS in 2008 and Cl in 2012 were significantly higher than in the other years. The average concentrations of TN, NO_3-N, and NH_3-N were highest in 2011, TDP was highest in 2010, and PP was highest in 2008 during rainfall runoff. Even though these 3 yr had the three highest annual flows (Table 3.8), the highest parameter concentrations were not significantly higher compared to many of the other years. During base flow, with no runoff contribution from the landscape, the average concentration of parameters varied less, resulting in fewer significant differences among years compared to the snowmelt and rainfall runoff events (Tables 3.9 and 3.10). However, the concentrations of NH_3-N and *E. coli* were significantly higher in 2011 compared to the other years during base flow.

The overall (i.e., all events) annual average concentrations for the N and P parameters and TSS were highest in 2011 and most (TP, NO_3-N, TP, TDP, PP, and TSS) were second highest in 2010 (Tables 3.9 and 3.10). In 2011, the concentrations of TN, NO_3-N, NH_3-N, and TDP were significantly higher than in the other years. The concentration of ON in 2011 was only significantly higher compared to 2007 and 2009. The concentrations of TP and PP in 2011 were significantly higher than in 2007, 2008, 2009, and 2012, but not significantly different from 2010. The largest annual flows (Table 3.8) and maximum peak flows (Figure 3.18) occurred in 2010 and 2011, suggesting higher concentrations of N, P, and TSS were the result of larger annual flows. The losses of TN and dissolved inorganic N (DIN) during wet periods have been attributed to increased N leaching and export during wetter climatic conditions in other studies (Donner et al., 2004; Donner and Scavia 2007; Nangia et al, 2010). Indianfarm Creek is a highly erosive creek, and with larger flows, more stream-bank erosion occurred. The overall average concentration of TSS in 2010 and 2011 was 1.3 to 5.2 fold greater compared to the other 4 yr. The 3 yr with the lowest annual flows (2007, 2009, and 2012) also had the lowest average TSS concentrations, though the concentrations in all 3 yr were not significantly different from 2008, and 2007 and 2012 were not significantly different from 2010. The effects of high flows on higher concentration of N, P, and TSS is contrasted by Cl, *E. coli*, and EC, which had the highest overall annual concentrations in years other than 2010 and 2011 (Table 3.10).

The relationship between flow and parameter concentration varied among the parameters, but concentration of all parameters was directly related to flow rate. The linear regression relationships were significant ($P < 0.1$) with r^2 values ranging from 0.03 to 0.71 (Table 3.11). The strongest relationships between flow and concentration were for TP, PP, TN, and TSS, and the N and P parameters were likely associated with the sediment. There were significant, but extremely weak relationships between flow and the concentration for *E. coli*, Cl, EC, and pH.

Figure 3.18. The outlet on (a) June 12, 2008 and (b) June 17, 2010. The difference in flow between the two dates can be seen at the sides of the concrete structure of the road bridge.

Watershed outlet mass loads. The annual nutrient and TSS mass loads at Station 1 generally increased with annual flow. The smallest mass loads occurred in 2007 and 2012, which also had the smallest flows (Table 3.12). Correspondently, 2010 and 2011 had the greatest loads and intermediate mass loads were calculated for 2008 and 2009. This suggests that flow was a primary driver for mass load differences among the low-, intermediate-, and high-flow years. Even with the low and intermediate categories, mass loads increased with annual flow. However, this was not the case for all parameters in 2010 and 2011. Annual flow was only 3% higher in 2010 compared to 2011. However, mass loads of TN and DIN were higher in 2011. Also, the mass loads of many of the other parameters were 57 to 94% higher in 2010 compared to 2011, proportionally much higher than the small difference in flow between the two years.

Table 3.11. Indianfarm Creek outlet (Station 1) flow and water quality parameter concentration linear regression relationships (n=128).

Parameter[z]	Linear equation	r^2
TP	y = 0.09x + 0.21	0.66*[y]
TDP	y = 0.02x + 0.09	0.26*
PP	y = 0.07x + 0.12	0.71*
TN	y = 0.34x +1.76	0.38*
ON	y = 0.13x + 1.28	0.37*
DIN	y = 0.22x + 0.49	0.25*
TSS	y = 61.6x + 71.8	0.59*
E. coli	y = 258x + 969	0.03*
EC	y = -17.0x + 732	0.11*
pH	y = -0.01x + 8.32	0.03*
Cl[x]	y = -0.16x + 9.71	0.04*

[z] TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TN = total nitrogen, ON = organic nitrogen, DIN = dissolved inorganic nitrogen (NO_3-N + NH_3-N), TSS = total suspended solids, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen, and Cl = chloride.
[y] * = significant at P <0.1.
[x] Chloride was added to the analytical suite in late July 2008.

Table 3.12. 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.

3.4.2.2 Watershed-wide Assessment

The average (2007 to 2012) concentration of TN and TP generally increased from the headwaters (Station 20) to the outlet (Station 1) for all event types (Figures 3.19 and 3.20). However, there were some deviations from this downstream increase in N and P concentrations. At Station 19 during snowmelt, the average concentrations of TN and TP were higher than the downstream stations. These averages were influenced by one sample, collected during an extremely low flow snowmelt event on March 6, 2007, which had the highest dissolved nutrient concentrations (12.6 mg L^{-1} DIN and 3.36 mg L^{-1} TDP) observed for this site during the study. When this sample was omitted, the average concentrations were reduced to 0.28 mg L^{-1} DIN and 0.09 mg L^{-1} TDP. At Station 12 during rainfall, PP and TSS concentrations were higher than the downstream stations (Stations 5 and 1) (Figures 3.20 and 3.21). The cause of the attenuation of PP and TSS concentrations from Station 12 to Station 5 is unknown. One possibility is that new beaver dams, which were established along this reach of IFC during the study, may have caused TSS and PP to settle from the flowing water.

The average (2007 to 2012) concentration of TN and TP generally increased from upstream (Station 14) to downstream (Station 3) in the western tributary (Figure 3.19 and 3.20), except for TP during rainfall runoff. Tributary average TN concentration was highest at Station 3 and lowest at Station 13 during all event types (Figure 3.19). The average TP concentration in the tributaries was highest at Station 3 and lowest at Station 13, except during rainfall runoff, when Station 13 had highest average concentration (Figure 3.20b).

The proportion of TN as DIN was generally higher during rainfall runoff compared to snowmelt runoff and base flow in the mainstem (Figure 3.19). From upstream (Station 20) to downstream (Station 1), the proportion of TN in the form of DIN ranged from 11 to 52% among the stations during rainfall runoff (Figure 3.19b). In comparison, TN concentration consisted of 11 to 31% DIN during snowmelt and 10 to 13% DIN during base flow (Figure 3.19a,c). Overall, the majority of TN was in the form of ON, which ranged from 60 to 88% of TN among the mainstem stations (Figure 3.19d). Similar to the mainstem stations, a higher proportion of TN was in DIN form for the tributary sites during rainfall runoff compared to snowmelt runoff and base flow. Over all, the tributary sites on average had a higher proportion of TN in the form of DIN (43%) compared to the mainstem stations (30%) (Figure 3.19d).

The proportions of TP as PP and TDP varied among event types and between mainstem and tributary sites (Figure 3.20). Among the mainstem stations, the proportion of TP as PP was 55 to 79% during rainfall events (Figure 3.20b), 54 to 81% for base flow (Figure 3.20c), and 31 to 55% during snowmelt events (Figure 3.20a). The lower proportion as PP during snowmelt was likely caused by frozen surface soil and less erosive conditions. Overall, a higher proportion of TP as PP was observed for Stations 16 to 1 compared to Stations 19 and 20 (Figure 3.20d). This was true for the three events types, particularly for rainfall events. This suggests the lower area of IFC Watershed downstream of Therriault Dam experienced higher erosion than the upper area of IFC Watershed. Differences in topography, land cover, and riparian health between the upper and lower regions may explain differences in erosion between the two regions. This was not unexpected, as high PP concentrations and lower TDP:TP ratios have previously been observed in similar streams as IFC with high erosion potentials in the grassland and continental divide ecoregions (Lorenz et al. 2008). Overall, the mainstem stations had a higher proportion of TP as PP compared to the tributary stations (Figure 3.20d). On average, TP concentration was 58% PP for the six mainstem stations and 45% for the three tributary stations. This difference was mainly affected by the western tributary (Stations 14 and 3); whereas, the central tributary (Station 13) was more similar to the mainstem.

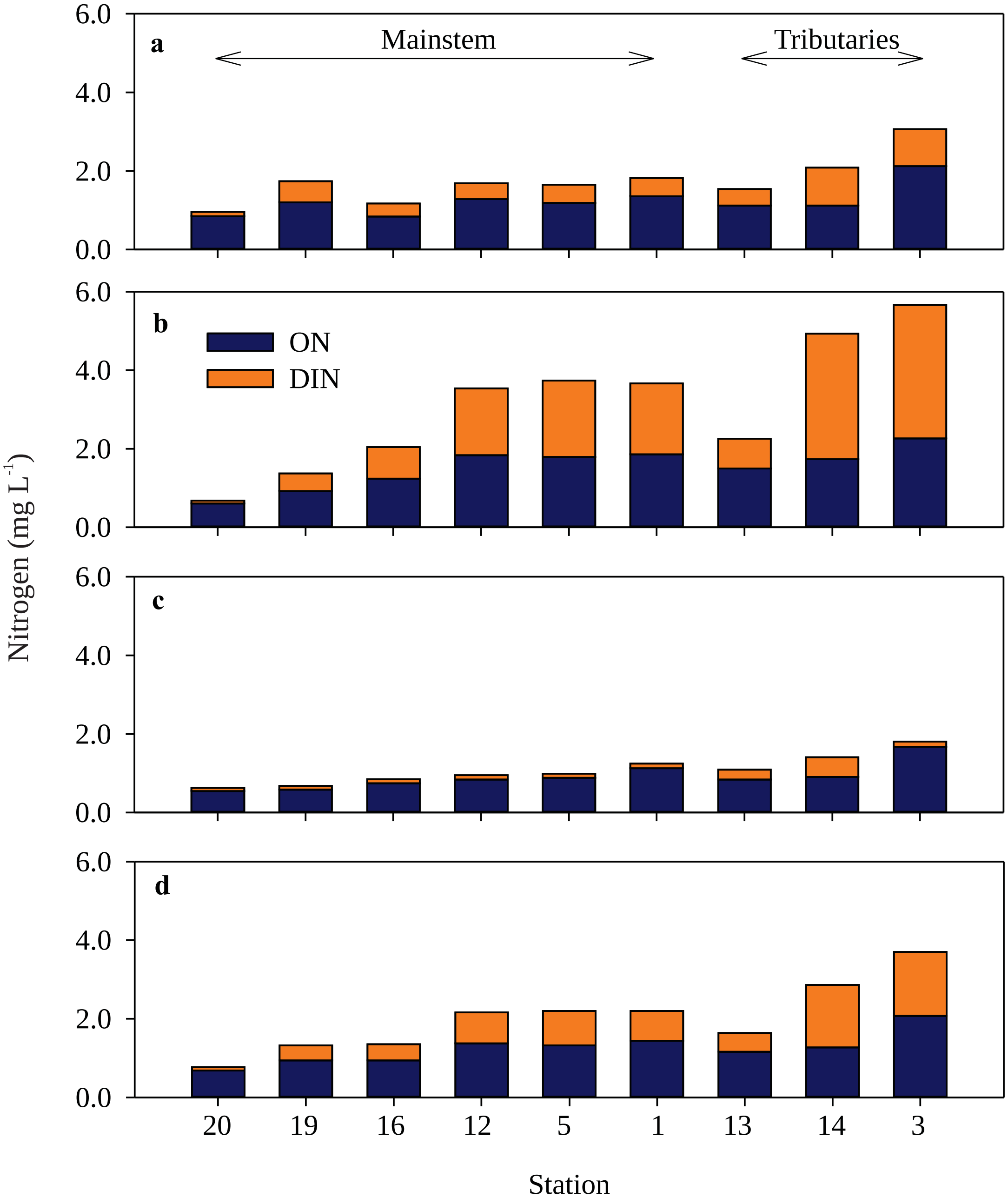

Figure 3.19. Average concentrations of organic nitrogen (ON) and dissolved inorganic nitrogen (DIN) during the study (2007 to 2012) for (a) snowmelt, (b) rainfall, (c) base flow, and (d) all events for the watershed-wide stations. The stack bars represents total N (ON plus DIN). The mainstem stations are shown from upstream (left) to downstream (right).

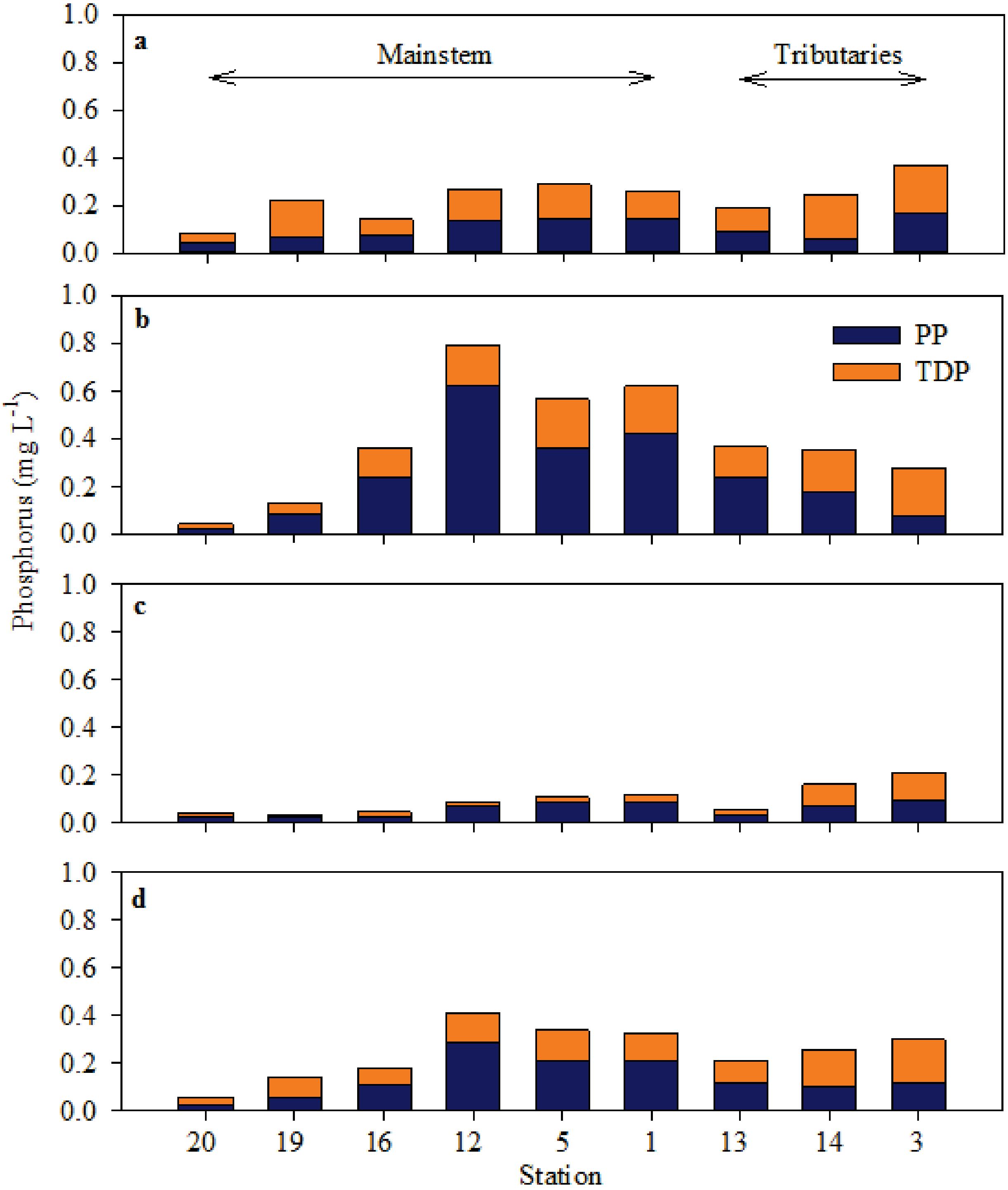

Figure 3.20. Average concentrations of particulate phosphorus (PP) and total dissolved P (TDP) during the study (2007 to 2012) for (a) snowmelt, (b) rainfall, (c) base flow, and (d) all events for the watershed-wide stations. The stack bars represents total P (PP plus TDP). The mainstem stations are shown from upstream (left) to downstream (right).

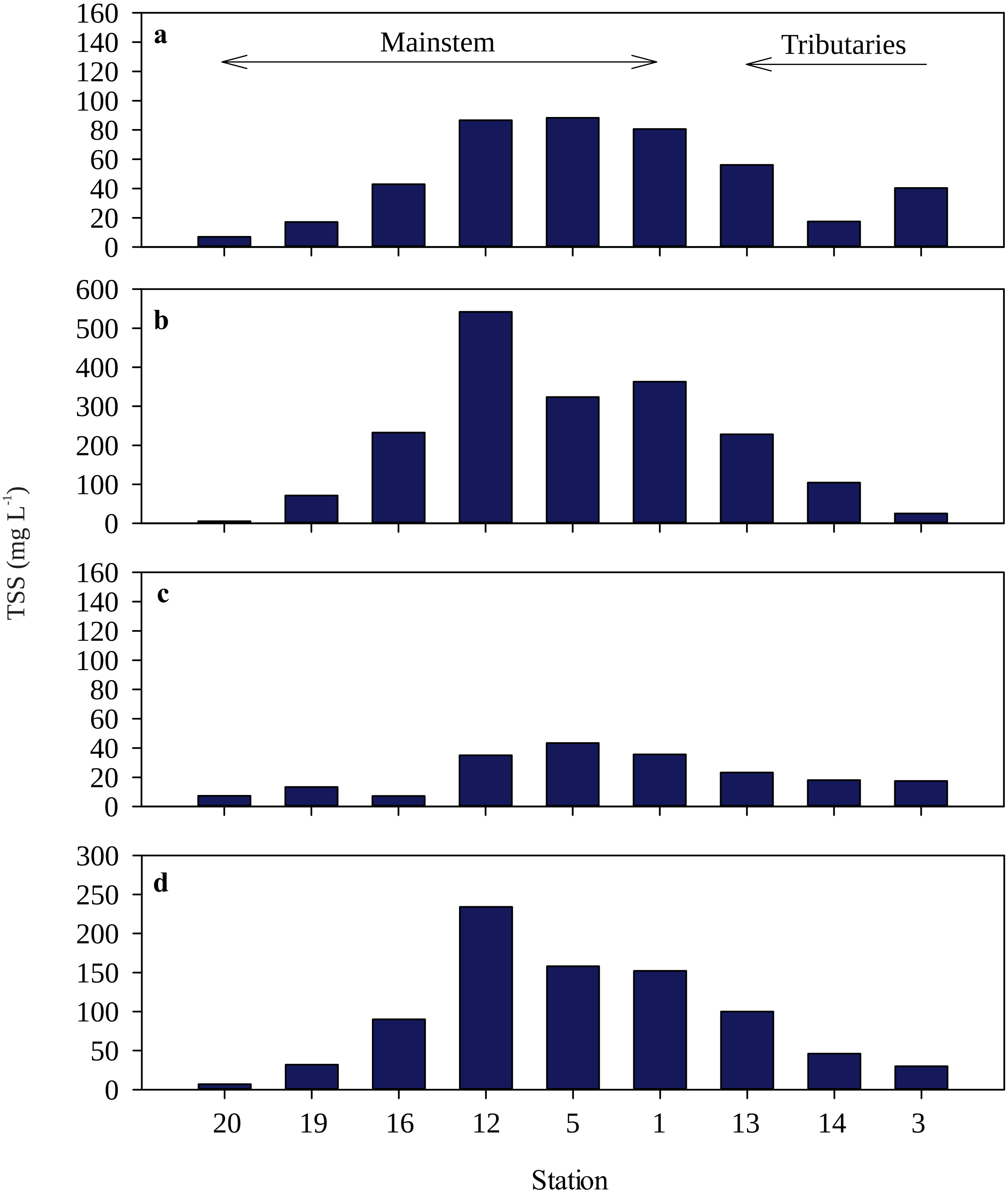

Figure 3.21. Average concentration of total suspended solids (TSS) during the study (2007 to 2012) for (a) snowmelt, (b) rainfall, (c) base flow, and (d) all events for the watershed-wide stations. The mainstem stations are shown from upstream (left) to downstream (right).

Not surprisingly, average TSS concentration patterns throughout the IFC watershed (Figure 3.21) were similar to PP concentrations (Figure 3.20). Generally TSS concentration increased from upstream (Station 20) to downstream (Station 1) on the mainstem. Higher TSS concentrations occurred during rainfall fall events, followed by snowmelt, and then by base flow conditions. The higher concentrations during rainfall were likely caused by higher volumes of runoff and water in the creek resulting in more stream-bank and instream erosion. Frozen soil conditions during snowmelt and smaller flows without runoff during base flow were likely factors for the lower TSS concentrations for these events types. The tributary stations had lower TSS concentrations than the downstream reach (Stations 12 to 1) of the mainstem. The lower concentrations in the tributaries were likely caused by smaller flows in the tributaries compared to the mainstem. During rainfall conditions, the average TSS concentration decreased by 4-fold from upstream (Station 14) to downstream (Station 3). This decrease in concentration may have been the result of the instream dam and the presence of an impoundment where TSS settled before exiting at Station 3.

Median concentrations of *E. coli* were highest during rainfall and lowest during snowmelt (Figure 3.22). This pattern reflects the seasonality of *E. coli* concentrations, which are typically higher in the summer months in agricultural watersheds (Lorenz et al. 2008). The highest *E. coli* concentration (160,000 mpn 100 mL^{-1}) occurred at Station 16 during rainfall runoff on July 13, 2009 (Figure 3.22b). On the IFC mainstem, median concentrations of *E. coli* were highest at Station 19 during all event types and may have been due to a small sheep farm and some cattle grazing upstream of this station (Figure 3.23). The largest increases in median concentrations of *E. coli* occurred between Stations 20 and 19; however, slight decreases occurred at Station 16 during base flow and snowmelt events, and this may have been due to settling and die off in the Therriault reservoir. The median concentration of *E. coli* was typically lower in the western tributary (Stations 14 and 3) compared to the mainstem stations, although the median concentrations at Station 3 were lower than upstream during all event types and this was likely due to sediment settling and die off in the Impoundment lake. The decreasing *E. coli* concentration trend downstream of an instream impoundment or dugout was also seen at the Feedlot BMP site (Sub-section 3.14.3.4). The concentration of *E. coli* in the central tributary (Station 13) was higher than the western tributary and higher than many of the mainstem stations.

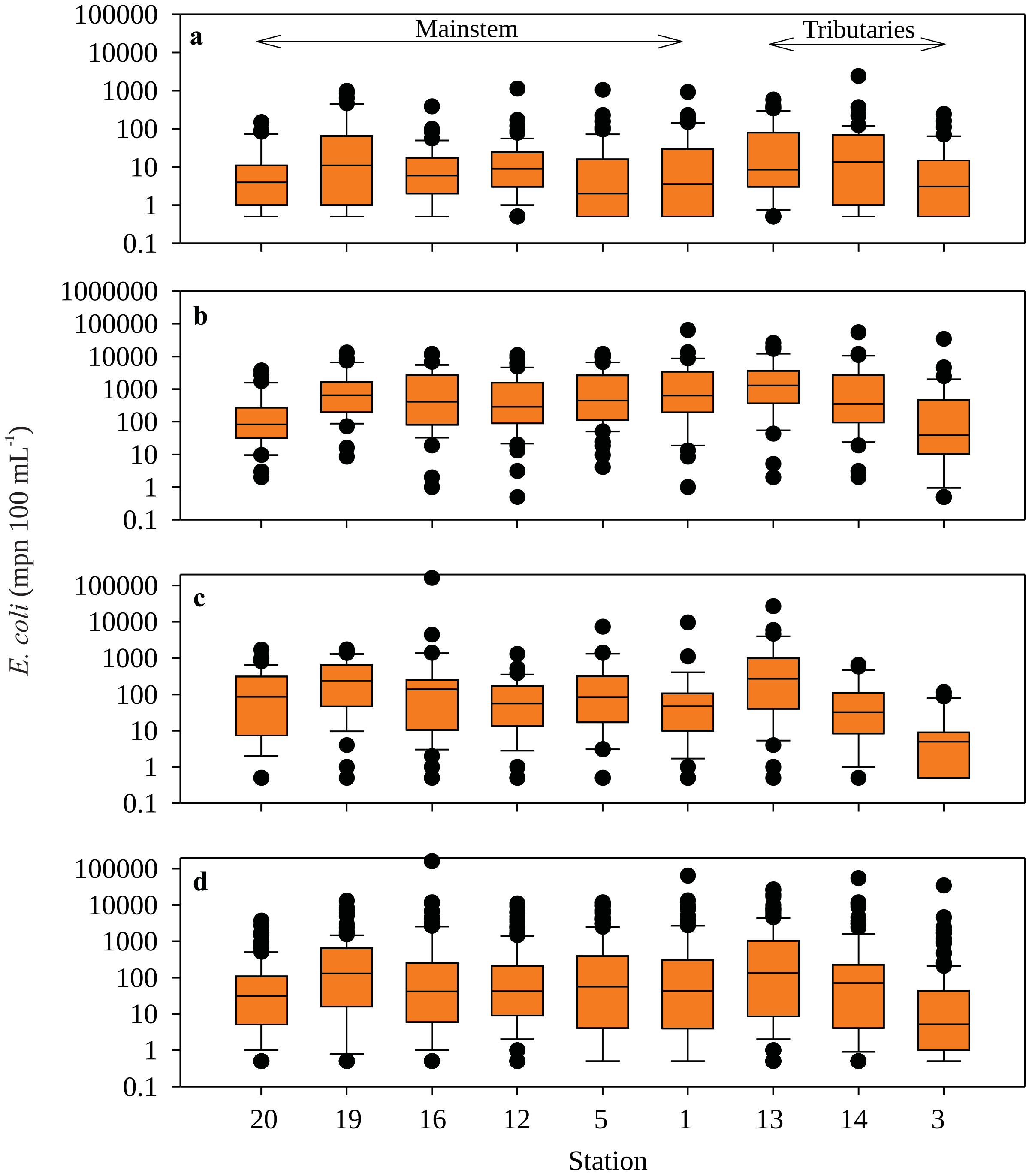

Figure 3.22. Box plots of *Escherichia coli* (*E. coli*) median, upper and lower quartile, minimum and maximum (T-bars), and outlier (black dots) concentrations for (a) snowmelt, (b) rainfall runoff, (c) base flow, and (d) all events for the watershed-wide stations from 2007 to 2012.

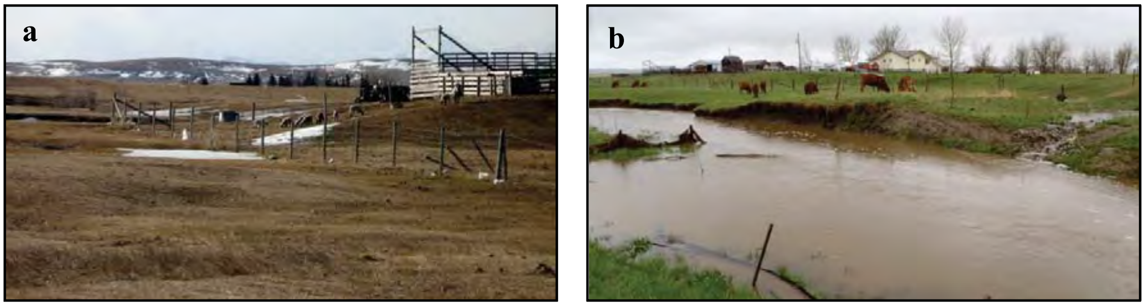

Figure 3.23. Images of the small farm located upstream of Station 19 (a) with sheep in corrals on March 7, 2007, and with (b) cattle grazing along the creek bank on May 24, 2011.

3.4.2.3 Nutrient Water Quality Sub-Index

The annual NWQS-I score for the watershed outlet was in the poor category (≤40) for five of the six study years (Figure 3.24a). The exception was in 2009 when a score of 45 placed the outlet water quality in the marginal category. The lowest NWQS-I scores occurred in 2010 and 2011, which were also the years with the largest annual flows (Table 3.8). The highest nutrient concentrations occurred in 2010 and 2011 and resulted in a greater number of exceedances of NWQS-I objectives. The annual average NWQS-I scores for all ten watershed-wide stations were similar with time as the outlet station, though the 2012 watershed-wide score was in the marginal category (Figure 3.24b). For most of the sites, the NWQS-I was higher in 2012 compared to the previous 2 yr (Figure 3.25). This was particularly true for the stations downstream of Therriault Dam. Flows were low in 2012, especially upstream from Therriault Dam, and nutrients may have been more concentrated in the headwaters compared to downstream of the dam. It is also interesting that even though the lowest average sub-index scores were in 2010 and 2011, the highest scores (good to excellent) at the headwater Station 20 occurred in these 2 yr (Figure 3.25).

The 6-yr average NWQS-I scores decreased from upstream to downstream on the mainstem of IFC (Figure 3.24c). The average score for Station 20 was in the fair category; whereas, all the other stations were rated poor. The drainage area upstream from Station 20 was in the foothills with relatively undisturbed land cover with some grazing pastures, and the creek was smaller and less incised. These conditions in the upper watershed likely resulted in better water quality at Station 20 compared to the rest of the watershed. The NWQS-I score decreased by 40% from Stations 20 to 19. Then the sub-index score only varied slightly from Stations 19 to 5. The lower sub-index score at Station 23 was likely due to the lack of water quality data from 2007 to 2009, resulting in the dataset for this station being influenced more by the two high-flow years of 2010 and 2011 compared to the other stations. After Station 5, the sub-index then decrease another 16% compared to the decrease from Stations 20 to 19. This further decrease in the NWQS-I downstream from Station 5 was likely caused by the contributions from the two main tributaries that entered the IFC between Stations 5 and 1 (Figure 3.15). The average NWQS-I scores for the three stations on these two tributaries were generally less than the sub-index scores for Stations 19 to 5 (Figure 3.24c). The tributary with Stations 3 and 14 likely had a more negative effect on water quality in IFC than the tributary with Station 13.

Overall, years with lower flow tended to have higher NWQS-I scores (i.e., better water quality) (Figure 3.24b). For some stations (Stations 16, 23, 12, 5) the highest score was in 2012 (Figure 3.25), which had the smallest flow and least amount of precipitation during the study.

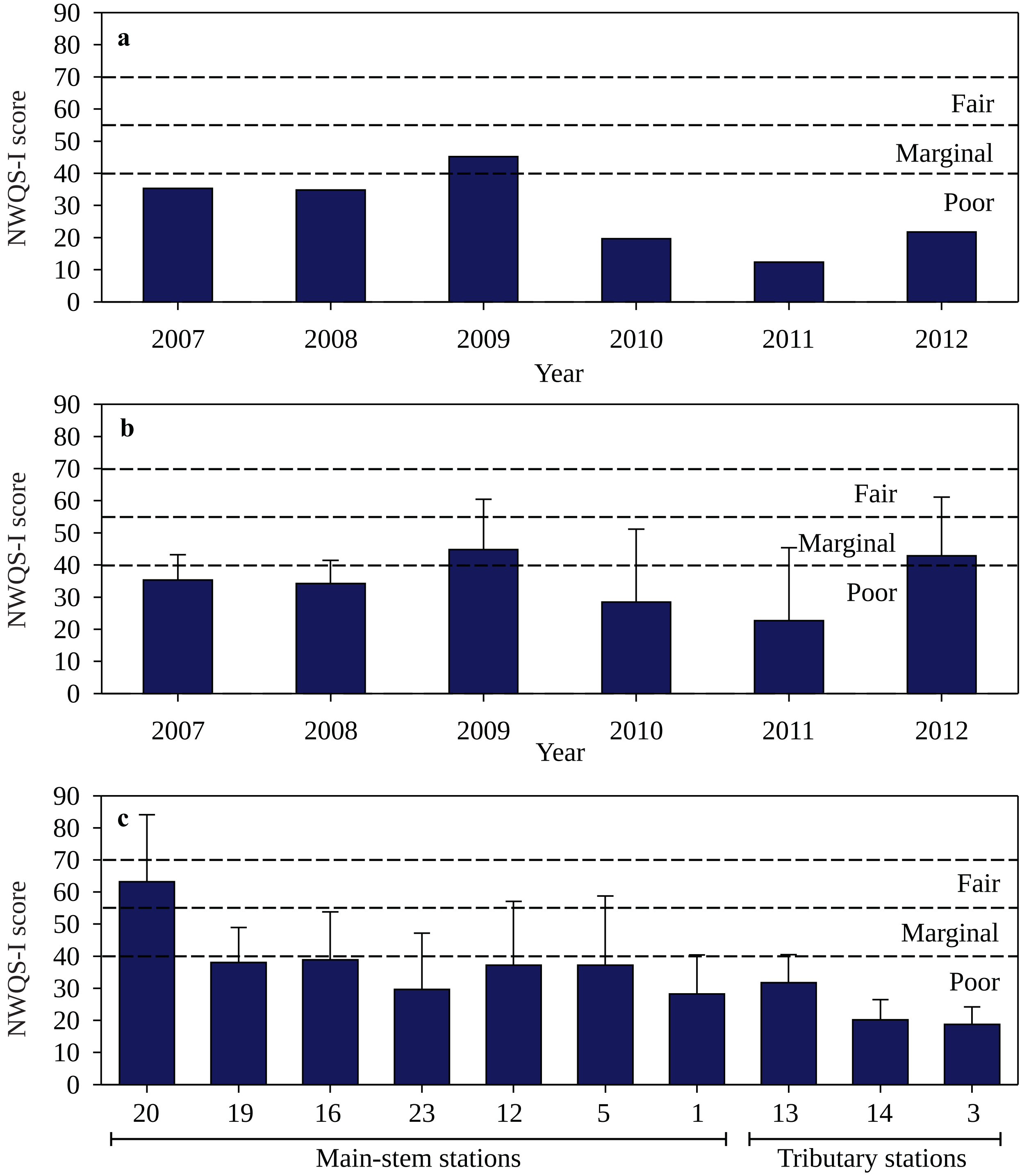

Figure 3.24. Nutrient water quality sub-index (NWQS-I) scores for (a) the watershed outlet at Station 1 from 2007 to 2012, (b) each year averaged among all of the watershed-wide stations (n =10), and (c) each station averaged among the years (n = 6). Score categories were poor (0 to 40), marginal (41 to 55), fair (56 to 70), good (70 to 85), and excellent (86 to 100). Note that Station 23 was added in 2010.

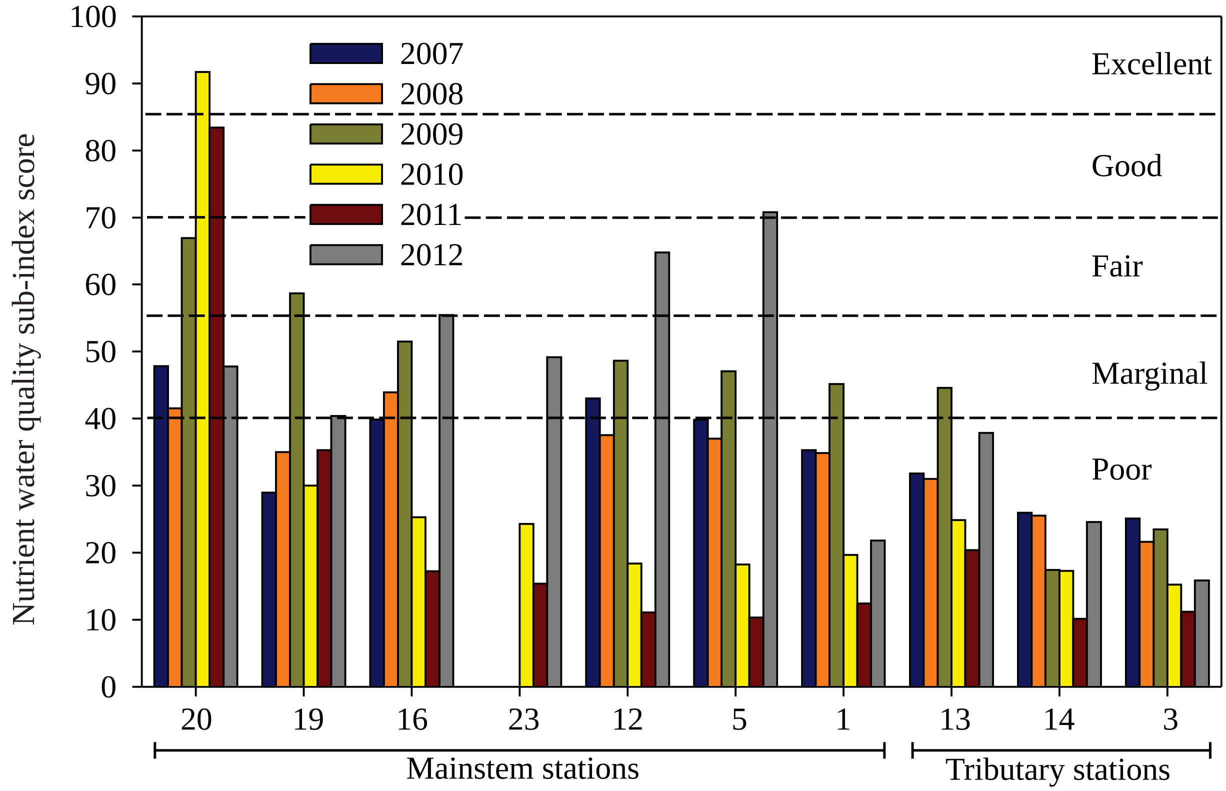

Figure 3.25. Nutrient water quality sub-index scores for the Indianfarm Creek watershed-wide water monitoring stations from 2007 to 2012. Score categories were poor (0 to 40), marginal (41 to 55), fair (56 to 70), good (70 to 85), and excellent (86 to 100). Note that Station 23 was added in 2010

3.4.2.4 Comparison to AESA Watersheds

The 6-yr median FWMCs of TP and TN at the outlet of IFC were 3- and 1.6-fold greater, respectively, than the medians for the 23 watersheds used in the AESA Water Quality Program from 1999 to 2006 (Lorenz et al. 2008) (Table 3.13). Similarly, the median mass loads of TP and TN were higher for the IFC outlet. The nutrient load and FWMC values in the AESA study may have underestimated actual nutrient export within these watersheds. The monitoring of AESA and BMP watersheds was designed to capture runoff events; however, the BMP study monitoring program was likely better at capturing these events because of the real time flow monitoring and fewer watersheds to coordinate for sampling.

Table 3.13. Total phosphorus (TP) and total nitrogen (TN) annual flow-weighted mean concentration and load median, minimum (Min.), and maximum (Max.) values for outlets of Indianfarm Creek (IFC) and the Alberta Environmentally Sustainable Agriculture (AESA) Program watersheds.

	Flow-weight mean concentration						Mass load					
	IFC[z]			AESA[y]			IFC[z]			AESA[y]		
	Median	Min.	Max.	Median	Min.	Max.	Median	Min.	Max.	Median	Min.	Max.
Parameter	(mg L^{-1})						(Mg)					
TP	0.6	0.2	1.5	0.2	0.0	1.3	3.5	0.07	36.6	1.2	0.002	70.6
TN	3.1	1.5	6.4	1.9	0.1	8.6	16.9	0.65	148.8	10.0	0.08	198.6

[z] Dataset from 2007 to 2012.
[y] Dataset for AESA watersheds from 1999 to 2006 (Lorenz et al. 2008).

The IFC Watershed was categorized as a moderate intensity agriculture watershed, based on the methodology used to categorize relative agriculture intensity for the 23 watersheds used in the AESA Program (Lorenz et al. 2008). Agriculture intensity categories (low, moderate, high) were based on manure production, fertilizer sales, and pesticide sales census data (Johnson and Kirtz 1998; Anderson et al. 1999). The TN and TP data for the IFC Watershed were generally between values obtained for the moderate and high agriculture intensity AESA watersheds (Figure 3.26).

3.4.2.5 Synoptic Survey

Low-flow synoptic survey. Flow at the mainstem sites upstream of Therriault Dam (Sites A to H) ranged from 0.029 to 0.038 $m^3 s^{-1}$; whereas, flow at the mainstem sites downstream of the dam (Sites J to X) ranged from 0 to 0.0025 $m^3 s^{-1}$ (Figure 3.27). Average flow for the mainstem sites

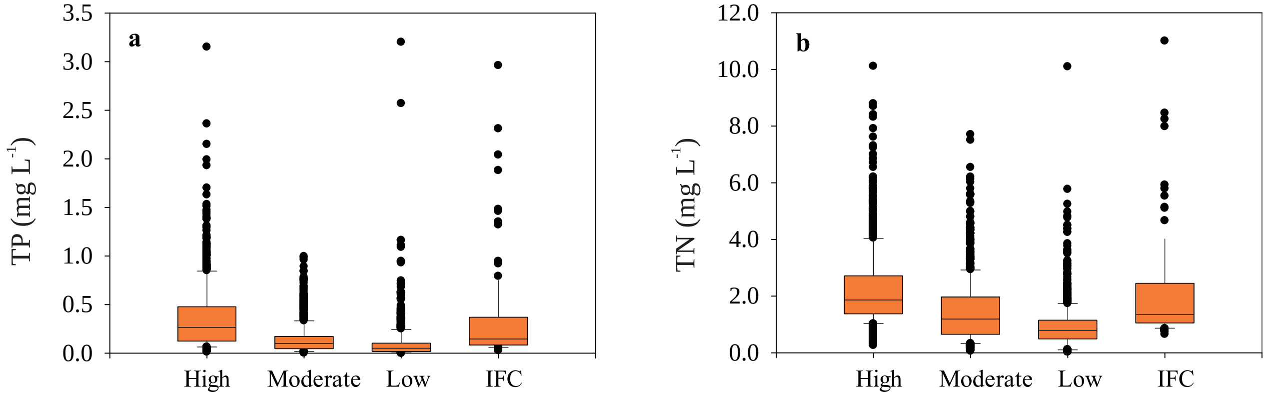

Figure 3.26. Instream concentrations of (a) total phosphorus (TP) and (b) total nitrogen (TN) in Indianfarm Creek (IFC) compared to values observed for high (eight watersheds), moderate (six watersheds), and low (five watersheds) agricultural intensity AESA watersheds (Lorenz et al. 2008). The four irrigated AESA watersheds were not included in these graphs. For a smaller y-axis and for ease of comparison among intensities, a TN concentration of 28 mg L^{-1} was not shown for the low intensity AESA watersheds in Figure 3.26b.

upstream of the dam was 23-fold greater than the downstream sites. There was no flow recorded at Site J immediately downstream of the dam. This suggests that, during the survey, no water was flowing from the dam, or the amount of water from the dam was too small to reach Site J and recharged groundwater instead. The flow at the mainstem sites was likely caused by groundwater discharge, with more discharge upstream from the dam (i.e., the upper region of the watershed).

Flow from the tributaries was very small during the survey. Three of the seven tributaries (F, N, Q) had no flow, and the flow values were less than 0.001 $m^3 s^{-1}$ for the other four tributaries. The average flow from all tributaries was six-fold less than for the mainstem sites downstream from the dam (Figure 3.27). Because of the very low flow in the tributaries, flow was difficult to measure. Compared to their respective upstream sites on the mainstem, Tributary C flow was 2% of the flow at Site B, and Tributary I flow was 0.3% of the flow at Site H (Figure 3.27). The two tributaries with flow downstream of the dam represented a higher proportions compared to the mainstem sites. Tributary T flow was 17% of the flow at Site S, and Tributary W flow was 39% of the flow at Site V.

Total N and P concentrations at the mainstem sites were consistently lower upstream of the dam, with less than 0.66 mg L^{-1} TN and less than 0.03 mg L^{-1} TP (Figures 3.28a and 3.29a). However, downstream of the dam, concentrations of TN and TP generally increased as water flowed towards the outlet. This increase was similar to the nutrient concentration observed during snowmelt in the

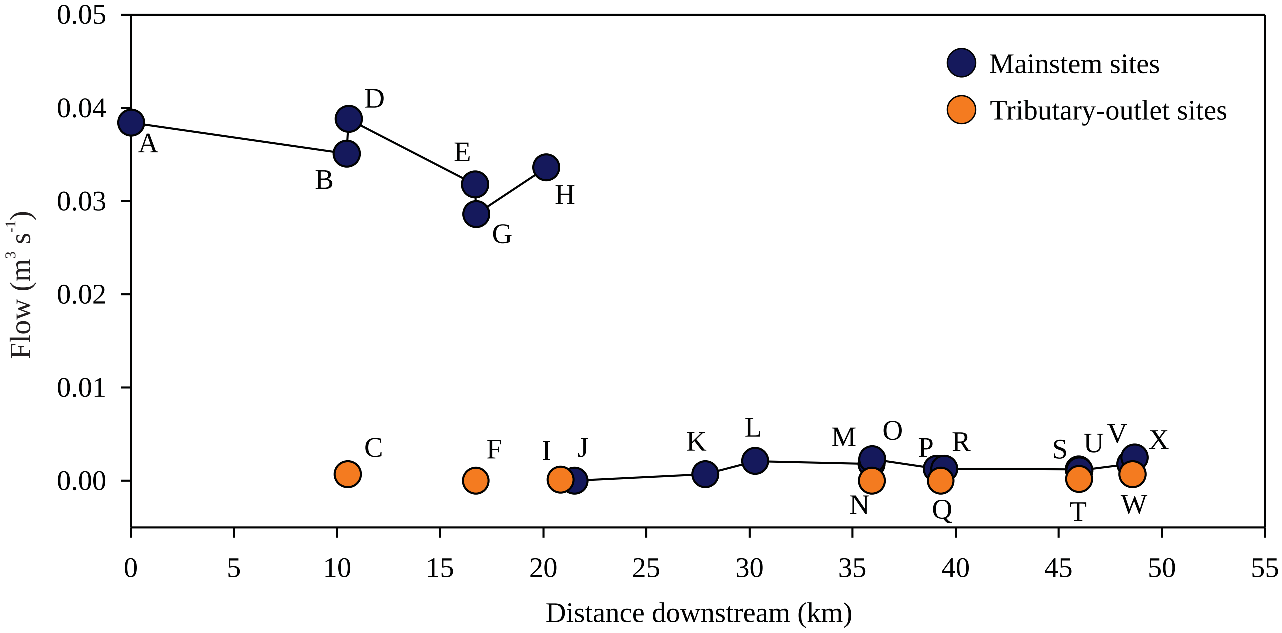

Figure 3.27. Flow in Indianfarm Creek during the low-flow synoptic survey carried out from May 12 to 16, 2008 from the headwaters (Site A) to the watershed outlet (Site X). The gap in the flow (between Sites H and J) indicates the location of Therriault Dam.

2008 watershed-wide assessment (data not shown). Tributary instream concentrations were generally higher compared to the mainstem sites, especially for Tributary I (Figures 3.28b and 3.29b).

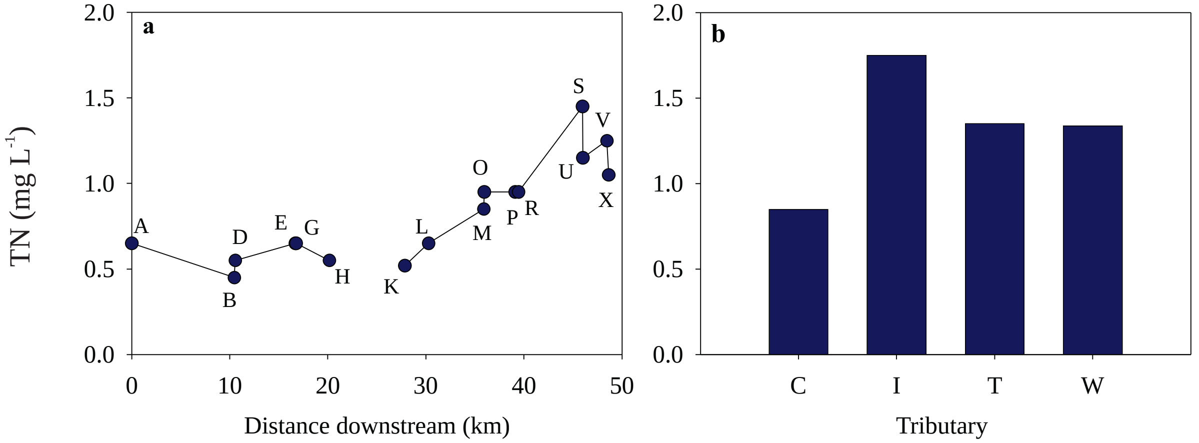

Figure 3.28. Total nitrogen (TN) concentrations on the (a) mainstem of Indianfarm Creek and (b) tributaries during the low-flow synoptic survey carried out May 12 to 16, 2008. In Figure 3.28a, sites are arranged from upstream (Site A) to downstream (Site X). The gap between Sites H and K represents Therriault Dam.

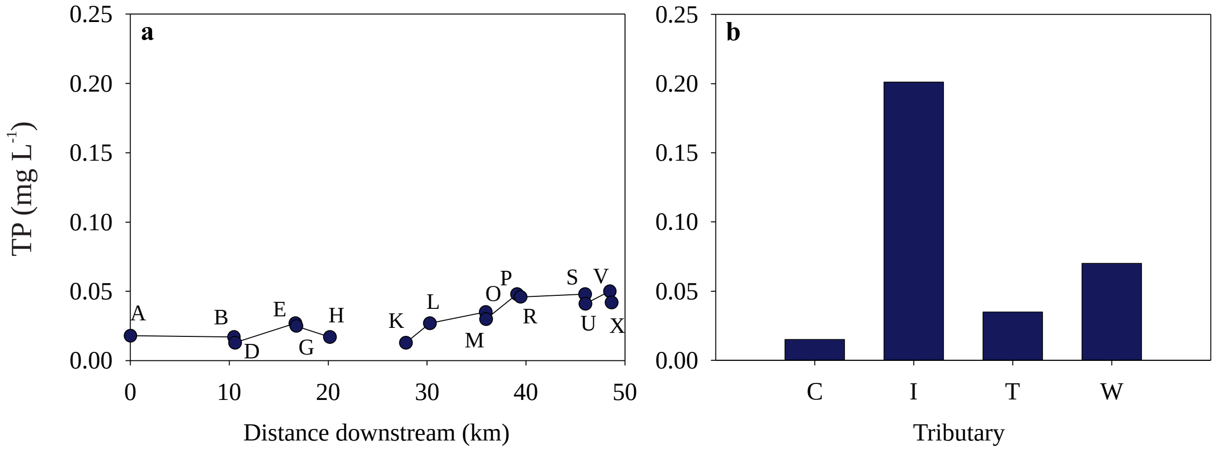

Figure 3.29. Total phosphorus (TP) concentrations on the (a) mainstem of Indianfarm Creek and (b) tributaries during the low-flow synoptic survey carried out May 12 to 16, 2008. In Figure 3.29a, sites are arranged from upstream (Site A) to downstream (Site X). The gap between Sites H and K represents Therriault Dam.

The concentration of TSS upstream of Therriault Dam was generally less than the method detection limit of 3 mg L^{-1}; whereas, TSS concentration increased downstream of the dam, with a maximum of 34 mg L^{-1} at Site V (Figure 3.30a). While TSS values were higher downstream of the dam, concentrations did not increase in a consistent manner from site to site. This may, in part, have been caused by pooled water during low-flow conditions. The overall increase in TSS concentration may have been related to slumping, erosion, and livestock activity (pugging) along the stream banks observed in this portion of the watershed.

The tributaries with flow had smaller concentrations of TSS compared to the corresponding upstream-downstream sites on the mainstem (Figure 3.30b). The higher proportion of flow at Tributaries T and W compared to the mainstem, may have contributed to the decrease in the TSS concentration from Sites S to U and from Sites V to X caused by a dilution effect.

After decreasing from Site A to Site B, the concentration of *E. coli* then increased from Site B to Site H (Figure 3.31a). For the most part, the concentration of *E. coli* on the mainstem was less than 30 mpn 100 mL^{-1} downstream of the dam, except for Site P, which had a concentration of 390 mpn 100 mL^{-1}. On average, *E. coli* concentration was higher in the upper region (113 mpn 100 mL^{-1}) of the watershed upstream of the dam compared to the lower region (52 mpn 100 mL^{-1}) of the watershed. The concentration of *E. coli* at the tributary sites was less than 30 mpn 100 mL^{-1} and similar to most of the mainstem sites (Figure 3.31b).

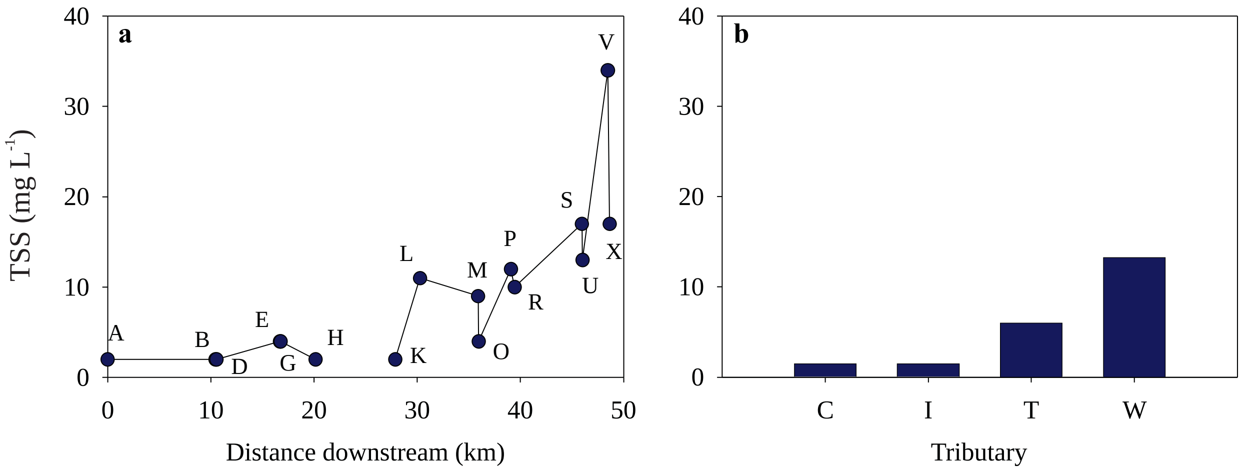

Figure 3.30. Total suspended solids (TSS) concentrations on the (a) mainstem of Indianfarm Creek and (b) tributaries during the low-flow synoptic survey carried out May 12 to 16, 2008. In Figure 3.30a, sites are arranged from upstream (Site A) to downstream (Site X). The gap between Sites H and K represents Therriault Dam.

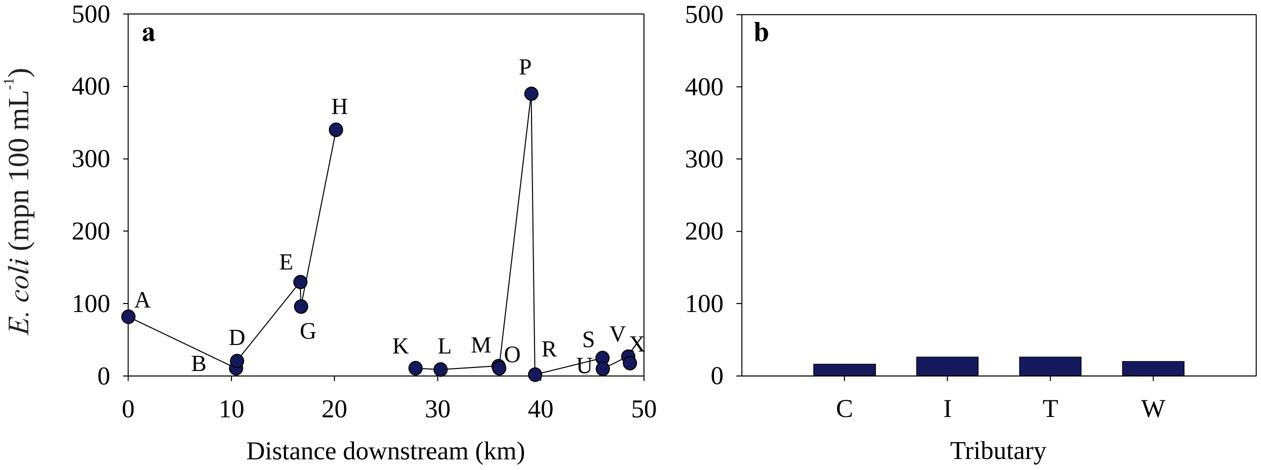

Figure 3.31. *Escherichia coli* (*E. coli*) concentrations on the (a) mainstem of Indianfarm Creek and (b) tributaries during the low-flow synoptic survey carried out May 12 to 16, 2008. In Figure 3.31a, sites are arranged from upstream (Site A) to downstream (Site X). The gap between Sites H and K represents Therriault Dam.

High-flow synoptic survey. Flow on the mainstem of IFC decreased slightly from Site A to Sites E, G, and H, with a range from 1.06 to 1.20 $m^3 s^{-1}$ (Figure 3.32). There was a general increase in flow downstream of Therriault Dam from Site J to Site X (outlet), with a range from 1.30 to 1.80 $m^3 s^{-1}$. All tributaries had much lower flow compared to the mainstem sites, and ranged from 0 to 0.1 $m^3 s^{-1}$. On average, the tributary flow values were about 3% of the flow values of the respective upstream sites on the mainstem. Of the seven tributaries, only Site Q had no flow into IFC during the high-flow synoptic survey. At three of the tributaries (Sites C, T, W), the flow was large enough to cause a measureable increase in flow from the upstream to downstream sites on the mainstem associated with these tributary sites. These increases ranged from 4 to 10%. There were no measureable increases in the mainstem at tributary Sites F and N. There was a large increase (25%) in flow from Sites H to J. This increase was primarily influenced by Therriault Dam, which was between these two sites. The contribution from the tributary measured at Site I (0.0099 $m^3 s^{-1}$), which entered Therriault Dam, was relatively small.

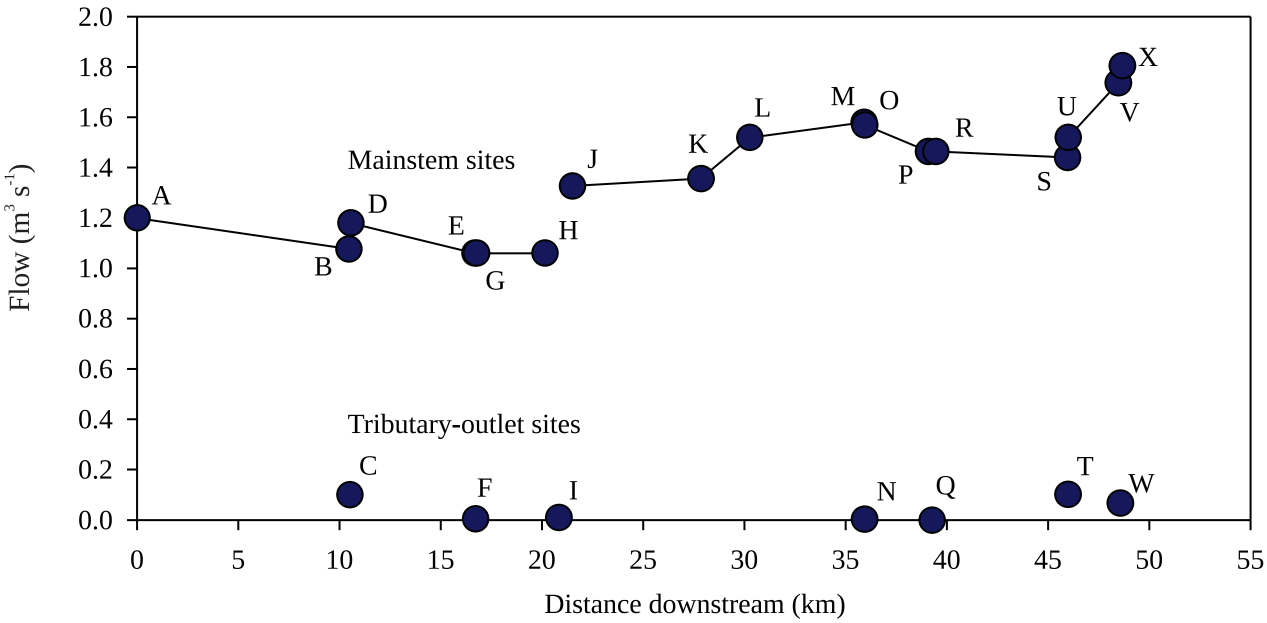

Figure 3.32. Flow in Indianfarm Creek during the high-flow synoptic survey carried out from May 26 to 27, 2008 from the headwaters (Site A) to the watershed outlet (Site X). The gap in the flow (between Sites H and J) indicates the location of Therriault Dam.

The concentration of TN and TP in the mainstem increased with distance downstream (Figures 3.33a and 3.34a). The increases in concentration were similar to average values found during the rainfall runoff watershed-wide data (Sub-section 3.4.2.2). In the reach upstream from Therriault Dam, the concentrations of TN and TP increased by about three-fold from Site A to Site H. At the watershed outlet (Site X), the concentration of TN was 3.7-fold greater and the concentration of TP was 6.9-fold greater compared to Site A. Total P concentration was similar immediately upstream (Site H) and downstream (Site J) of the dam (0.19 mg L^{-1}), and the overall increase in concentration was generally steady throughout the mainstem. In contrast, TN concentration decreased immediately downstream of the dam, suggesting the dam had a reducing effect on TN concentration. However, this was just a one-time sampling, and 6 yr of watershed-wide data did not support this effect of the dam (i.e., comparing Stations 19 and 16). Total N concentration then increased slightly from Site J to Site R followed by a large increase from Site R to Site S. The cause of the increase from Site R to Site S is unknown as there were no major tributaries flowing into IFC between these two sites.

Site I had particularly high TN (6.05 mg L^{-1}) and TP (1.36 mg L^{-1}) concentrations (Figures 3.33b and 3.34b). The Site I tributary was within a pasture area. The concentrations of TN and TP at tributary Sites C, F, I, and N were greater than at the respective upstream and downstream mainstem sites. In contrast, TN and TP concentrations were less at the tributary Sites T and W compared to their respective upstream and downstream sites. Therefore, it would be expected that contributions from Tributaries C, F, I, and N would have caused an increase in concentration in the mainstem; whereas, Tributaries T and W would have caused a decrease in concentration. However, the effects of tributaries on the mainstem concentrations were inconsistent. Instream TP concentration increased at Site G and Site U, which were downstream of Tributaries F and T, respectively. Instream TN concentrations increased at Sites D and G, which were downstream from Tributaries C and F, respectively. At the other tributary sites, there was either a decrease or little change from upstream to downstream on the mainstem. Any potential influence of Tributary I was likely masked by Therriault Dam. The relatively small flows from the tributaries compared to the mainstem made it difficult to measure a consistent effect on TN and TP concentrations in the mainstem.

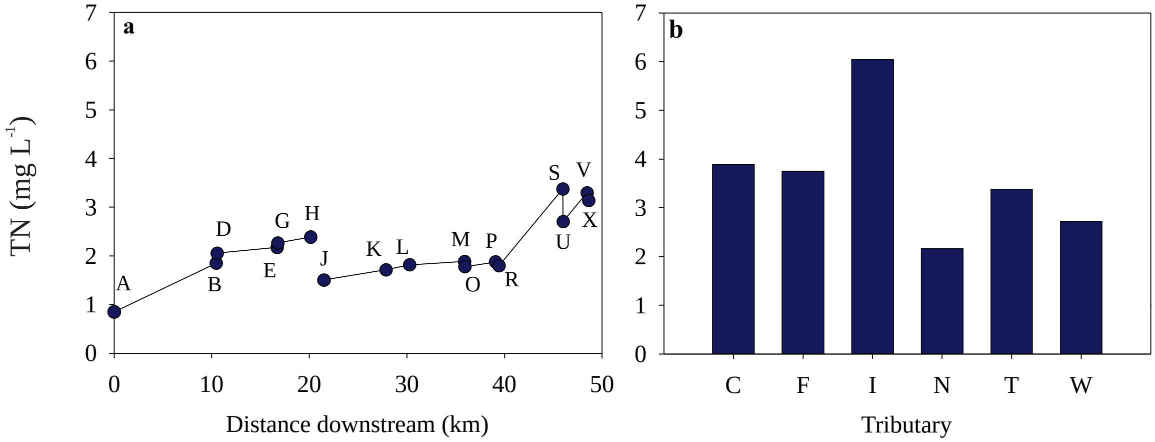

Figure 3.33. Total nitrogen (TN) concentrations on the (a) mainstem of Indianfarm Creek and (b) tributaries during the high-flow synoptic survey carried out May 26, 2008. In Figure 3.33a, sites are arranged from upstream (Site A) to downstream (Site X). The gap between Sites H and J represents Therriault Dam.

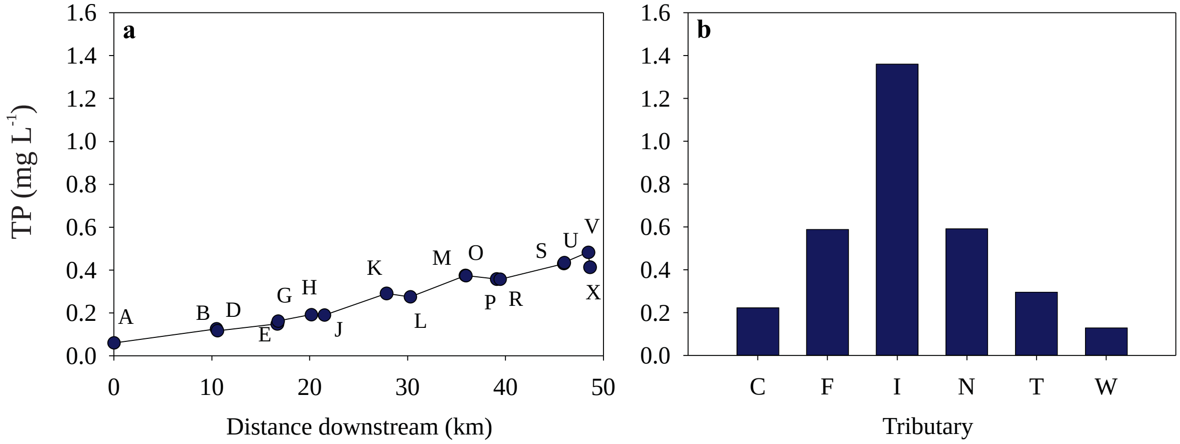

Figure 3.34. Total phosphorus (TP) concentrations on the (a) mainstem of Indianfarm Creek and (b) tributaries during the high-flow synoptic survey carried out May 26, 2008. In Figure 3.34a, sites are arranged from upstream (Site A) to downstream (Site X). Therriault Dam was between Sites H and J.

Total suspended solids concentration increased as water flowed downstream during the high-flow synoptic survey (Figure 3.35a). The concentration of TSS ranged from 3 mg L^{-1} (Site A) to 400 mg L^{-1} (Site V) on the mainstem of IFC. The rate of increase in TSS concentration was greater downstream (Sites J to X) of Therriault Dam compared to the upstream reach (Sites A to H). Based on linear regression analysis for the two reaches, the rate of increase per unit distance for the downstream reach was 3.4-fold greater compared to the upstream reach. Greater flow values in the downstream reach (Figure 3.31) may have contributed to greater erosion of creek banks, thereby increased the sediment concentration at a greater rate. Also, creek banks may have been more degraded, and more susceptible to erosion, due to more cattle activity in the riparian areas downstream of the dam.

The concentration of TSS was less in the tributaries compared to the mainstem sites (Figure 3.35a,b). Generally, TSS concentration increased the closer the tributary was to the outlet of the watershed, with the exception of Site W, which decreased in TSS concentration (Figure 3.35b). About 340 m upstream from Site W on the tributary was an on-stream earth dam, which created a small lake. A large proportion of sediment in this tributary likely settled in the lake before reaching Site W at the tributary's outlet. The flow values of the tributaries were much less than for the mainstem sites (Figure 3.32), and may have caused less erosion in the tributaries. There was a decrease in TSS concentration from the upstream to downstream sites associated with each tributary site. This suggests that the tributaries caused a dilution effect on TSS concentration on the mainstem. This effect was also observed for Sites P and R, which were associated with Tributary Q. However, Tributary Q did not flow during the high-flow synoptic survey, and therefore, could not have been the cause of the apparent dilution effect at this site. Regardless whether the tributaries had measureable effects on TSS concentration in the mainstem, the effects were dominated by the TSS contributions within the mainstem itself.

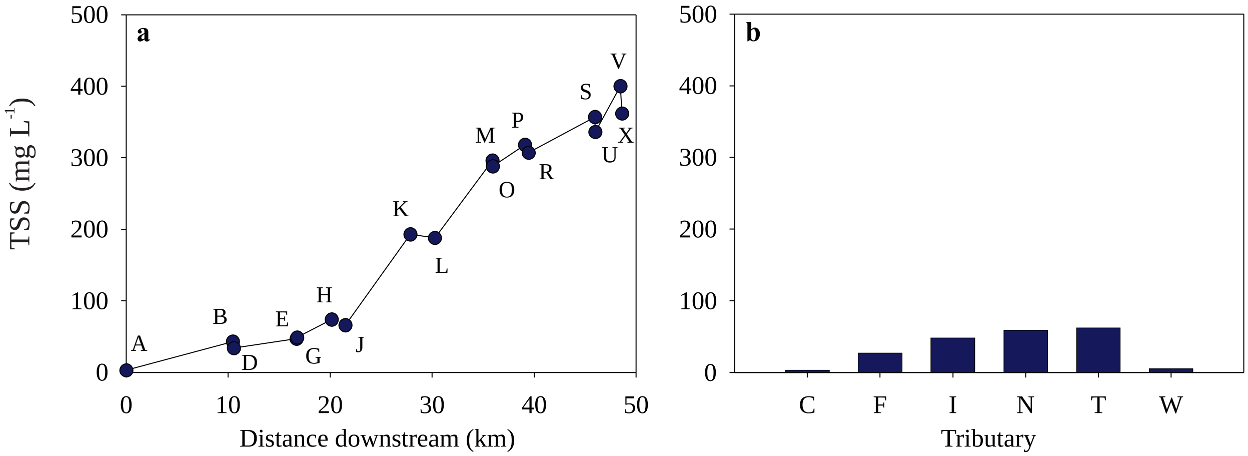

Figure 3.35. Total suspended solids (TSS) concentrations on the (a) mainstem of Indianfarm Creek and (b) tributaries during the high-flow synoptic survey carried out May 26, 2008. In Figure 3.35a, the sites are arranged from upstream (Site A) to downstream (Site X). Therriault Dam was between Sites H and J.

The concentration of *E. coli* increased from Site A to Site H upstream from Therriault Dam (Figure 3.36a). Then the concentration decreased at Site J, immediately downstream from the dam, suggesting the dam had a reducing effect on *E. coli* concentration. There was a large increase in concentration from Site J to Site K and concentration remained relatively high for the remainder of the mainstem compared to the reach upstream from the dam (Sites A to H).

Concentrations of *E. coli* at the tributary sites were either less than the immediate upstream mainstem sites (Tributaries C, T, W) or greater than the immediate upstream mainstem sites (Tributaries F, I, N) (Figure 3.36a,b). Tributary N had the highest *E. coli* concentration among the tributaries (Figure 3.36b), and may have been caused by a cattle feeding and bedding site adjacent to a feedlot located about 400 m upstream on Tributary N.

The potential impact of the tributaries on *E. coli* concentration in the mainstem was not consistent. For example, the lower concentration in Tributary C compared to Site B may have caused the reduction at Site D. Whereas, the much larger concentration at Tributary N compared to Site M did not result in an increase at the downstream Site O. Also, there was a decrease in concentration from Site P to Site R even though Tributary Q was dry and did not contribute to the creek during the survey.

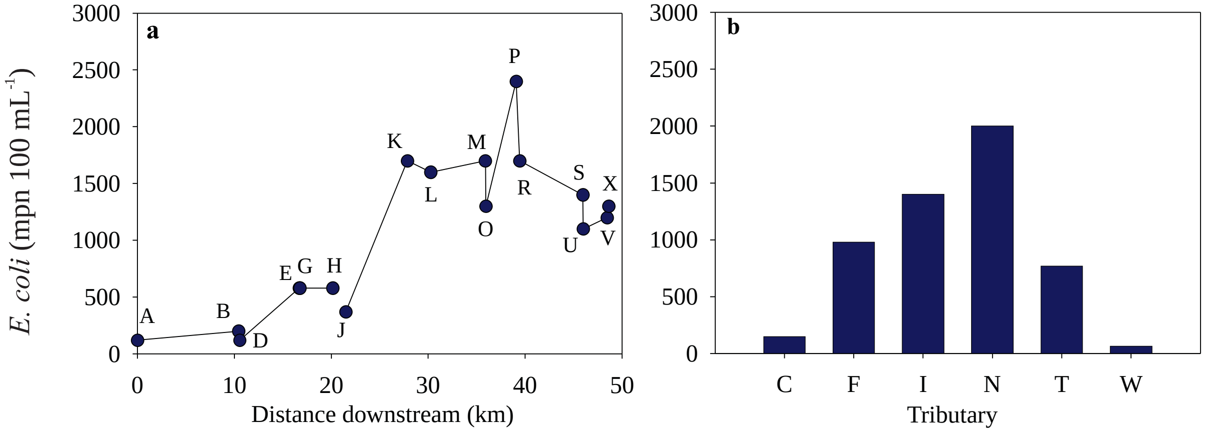

Figure 3.36. *Escherichia coli* (*E. coli*) concentration on the (a) mainstem of Infianfarm Creek and (b) tributaries during the high-flow synoptic survey carried out May 26, 2008. In Figure 3.36a, the sites are arranged from upstream (Site A) to downstream (Site X). Therriault Dam was between Sites H and J.

Comparing low- and high-flow synoptic surveys. The average flow among the mainstem sites for the high-flow synoptic survey was more than 100-fold greater than the average flow observed for the low-flow synoptic survey (Figures 3.27 and 3.32). The average flow for the tributary sites was 220-fold greater during the high-flow synoptic survey compared to the low-flow synoptic survey. The velocity of water in the mainstem was calculated at 0.7 km h^{-1} upstream of the dam and 0.6 km h^{-1} down of the dam during the low-flow survey (Tables 3.5 and 3.6). The velocity of water in the mainstem was calculated at 1.8 km h^{-1} upstream of the dam and 1.2 km h^{-1} downstream of the dam during the low-flow survey (Tables 3.5 and 3.6).

The flow at the outlet (Site X) was 1.8 m^3 s^{-1} during the high-flow synoptic survey near the end of May 2008 (Figure 3.32). In comparison, the average flow at the outlet for the month of May measured from 2007 to 2012 for the watershed-wide assessment ranged from <0.0001 to 2.67 m^3 s^{-1}. The outlet flow value during the high-flow synoptic survey was greater than the May averages for 2007 (0.09 m^3 s^{-1}), 2008 (0.52 m^3 s^{-1}), 2009 (0.51 m^3 s^{-1}), and 2012 (<0.0001 m^3 s^{-1}), and was less than the May averages for 2010 (2.67 m^3 s^{-1}) and 2011 (2.59 m^3 s^{-1}). Even though there were much larger peak flows in 2008, 2010, and 2011 (Figure 3.16), the value measured during the high-flow synoptic survey at the outlet was typical for IFC, and in fact was higher than any flow measured in 2007, 2009, and 2012 (Figure 3.16). In contrast, the flow at the outlet during the low-flow synoptic survey (0.0025 m^3 s^{-1}) was much less than the May averages from 2007 to 2011. There was essentially no flow during May 2012, except on two consecutive days in the month.

The concentrations of TN, TP, TSS, and *E. coli* were all higher during the high-flow synoptic survey compared to the low-flow synoptic survey for nearly all sampling sites that had flow during both surveys (Figures 3.28 to 3.31 and 3.33 to 3.36). The only exception was for TSS at Site W, which had about 13 mg L^{-1} TSS during low flow and 5 mg L^{-1} TSS during high flow. On average among all sites with flow during both surveys, concentration was 2.9-fold greater for TN, nine-fold greater for TP, 25-fold greater for TSS, and 92-fold greater for *E. coli* during the high-flow survey compared to the low-flow survey.

For the most part, there were no trends or bias of increased concentration from low- to high-flow conditions in terms of mainstem versus tributary, distance along the reach, or water quality parameter, expect for Site A and *E. coli* concentration. For three parameters (TN, TSS, *E. coli*), the smallest increases (1.3- to 1.5-fold) occurred at Site A, and for TP, Site A had the second smallest increase (3.3-fold) in concentration during high flow compared to low flow. This may suggest that water quality in the headwaters in the upper region of the watershed was less influenced by an increased in flow compared to rest of the watershed. Perhaps the landscape in the upper headwaters had a greater buffering capacity against nutrient and sediment loss because of less impact by agriculture activity compared to the rest of the watershed, which was more impacted by agricultural land use.

Of the four parameters (TN, TP, TSS, *E. coli*), the increase in *E. coli* concentration from low- to high-flow conditions was more apparent in the reach downstream from Therriault Dam. For Sites A to I, average *E. coli* concentration was 13-fold greater during high flow; whereas, for Sites K to X, average *E. coli* concentration was 145-fold greater during high flow. The larger increase downstream of the dam (i.e., lower region of the watershed) may have been due to more livestock activity and direct access to the mainstem and tributaries compared to the upper region.

3.4.2.6 Streambed Sediment

The concentration of STP in sediment samples collected in fall 2008 ranged from 1 to 42 mg kg^{-1}, with an overall average of about 10 mg kg^{-1} (Table 3.14). Most of the sediment samples had less than 10 mg kg^{-1}, which is considered low in field soils for the agronomic requirements of crops. The PSI values were relatively high, ranging from 124 to 509 mg kg^{-1} (Table 3.14). On the other hand, DPS was low for all samples, with 17% the highest value, and most samples were less than 5% DPS. These results suggest that sediment in the drainage channels was low in P and was not a major source of P in terms of desorption from sediment material into the water column. Soils with DPS values from 25 to 40% are considered to have a greater risk of P loss to runoff water (Pautler and Sims 2000). Most of the DPS values for the IFC sediment samples were less than those found in manured and non-manured crop fields (4 to 94%) in Alberta reported by Casson et al. (2006). The low DPS values indicate that channel sediment in IFC and tributaries have a large capacity to sorb P.

Table 3.14. Channel width, soil-test phosphorus (STP), phosphorus sorption index (PSI), and degree of phosphorus saturation (DPS) for channel sediment samples collected throughout Indianfarm Creek Watershed on September 25, 2008.

Site or station[z]	Channel width (m)	STP (mg kg^{-1})	PSI (mg kg^{-1})	DPS (%)
A(20)	3.2	4.40	478	0.9
B	5.5	3.64	326	1.1
C[x]	3.0	2.69	216	1.2
D	2.8	2.68	229	1.2
E	2.3	2.47	207	1.2
18[y, x]	1.6	34.3	365	8.6
F[y]	1.5	20.5	304	6.3
G	3.2	4.31	179	2.3
I[y]	2.9	30.4	327	8.5
J	0.8	19.0	460	4.0
K	3.1	3.89	169	2.3
L	4.0	1.69	192	0.9
N	5.3	2.93	293	1.0
O	1.8	5.78	478	1.2
12	5.1	3.68	340	1.1
10[y]	4.7	41.9	199	17.4
8	3.1	2.35	267	0.9
5	2.7	1.41	255	0.5
S	5.1	6.05	303	2.0
13[y,w]	3.1	1.77	124	1.4
T[y]	3.0	3.20	276	1.1
U	2.9	3.73	286	1.3
14[y,v]	4.5	9.26	301	3.0
21[y,v]	5.8	17.7	509	3.4
W[y]	1.3	9.89	401	2.4
Average ± SD[u]	3.3 ± 1.4	9.58 ± 11.3	299 ± 104	3.0 ± 3.7

[z] Site refers to synoptic survey sites and station refers to water monitoring stations.
[y] Tributary sites or stations.
[x] Station 18 is upstream from Site F on the same tributary.
[w] Station 13 is upstream from Site T on the same tributary.
[v] Stations 14 and 21 are upstream from Site W on the same tributary.
[u] SD = standard deviation.

The two sites with the highest DPS values (Stations 10 and 18) were not part of the watershed-wide monitoring or synoptic surveys. These stations were used for two BMP sites: Station 10 for the Pasture site (Sub-section 3.7) and Station 18 for the South Manure Field site (Sub-section 3.9). Both stations were on small, vegetative, drainage channels. Station 10 was on a channel within a native pasture and Station 18 was on a grassed channel that bisected annually cropped land upstream of synoptic survey Site F. These two sites also had the highest STP concentration, which likely reflected local land use and channel characteristics. The vegetative cover of the channels may have trapped sediment and accumulated plant residue material and caused a modest accumulation of P. Station 10 may have also been affected by fecal pats from grazing cattle. Station 18 was impacted by runoff entering the channel from surrounding cropped land and from a calving site upstream on the channel.

Upstream from Therriault Dam, Sites F and I had the next two highest DPS values (Table 3.14). Tributary F flowed into IFC approximately 50 m upstream of Site G, while Tributary I flowed directly into Therriault Dam (Figure 3.15). Both tributaries may have been impacted by cattle activity. Sites F was in a livestock pasture and feeding area near barns and farmyard, and this area was significantly degraded (Figure 3.37). Tributary I was about 5 km downstream of a feedlot operation on the tributary. The results for Sites F and I, as well as for Stations 10 and 18, suggest that smaller, more vegetative drainage channels impacted by agricultural activity may have higher DPS values, compared to the larger, more defined creek channels. The mainstem and larger tributaries were scoured and flushed by larger flows, and this may have prevented the accumulation of sediment saturated with P in creek channels. The relatively low DPS of the sediments suggests the IFC channel is not a major source of desorbed P into the water; and as described previously, erosion and losses of PP are more of a concern in IFC Watershed.

Figure 3.37. Site F and tributary in a cattle pasture downstream from a farmyard. The outlet of the tributary into Indianfarm Creek was a few metres to the left of the image. Image taken May 1, 2008.

3.4.3 Conclusions

Watershed Outlet:

- During the 6-yr study, flow at the watershed outlet ranged from 0.3 million to 23.8 million m^3 yr^{-1}. The smallest flows occurred in 2007 and 2012 and the highest flows occurred in 2010 and 2011. Most flow occurred from March to July as a result of spring snowmelt and spring rainfall, and the mainstem of the IFC did not flow in the latter half of each year.
- The wide range in annual flows among the 6 yr was largely driven by the amount of total precipitation. Total precipitation was the highest in 2010; whereas, the two driest years were 2007 and 2012, which also had the lowest annual flows.
- Above average precipitation in 2010, particularly in September and October, may have caused higher antecedent soil moisture in 2011, and this may have contributed to more runoff and high flows in 2011.
- On average, 25% of annual flow at the watershed outlet occurred during snowmelt. The remaining 75% was caused by rainfall and base flow, of which rainfall appeared to be more dominant based on field observations.
- The average concentration of most water quality parameters (TN, ON, NO_3-N, all P parameters, TSS, and *E. coli*) were highest during rainfall events. The concentration of most parameters was lowest during base flow, except for *E. coli*, which was lowest during snowmelt, and this was expected because of less microbial activity during the colder conditions of snowmelt.
- The majority of TP and TN in water was in particulate form, with 65% of TN as ON and 64% of TP as PP on average. This reflects the erosive nature of IFC and a majority of N and P are transported as part of the sediment material. Therefore, management change that can reduce stream bank erosion caused by agricultural activity may reduce the amount of nutrients that enter the creek.
- Annual average concentrations of all N and P parameters and TSS were highest in 2011. The next highest average concentrations for most of these parameters (TP, NO_3-N, TP, TDP, PP, TSS) were observed in 2010. Also, the TN, NO_3-N, and NH_3-N concentrations were significantly higher in 2011 than the other study years. Therefore, higher concentrations in 2010 and 2011 were the result of larger annual flows compared to the other 4 yr.
- The concentration of all water quality parameters was directly related to flow rate. The linear regression relationships were significant ($P < 0.1$) with r^2 values that ranged from 0.03 to 0.71. The strongest relationships between flow and concentration were for TP, PP, TN, and TSS. The relationships were very weak between flow and the concentration for *E. coli*, Cl, EC, and pH (r^2 = 0.03 to 0.11).
- Flow was a primary driver for mass load differences among the low-, intermediate-, and high-flow years. The smallest mass loads were in 2007 and 2012 (low-flow years) and the largest loads were in 2010 and 2011 (high-flow years).

Watershed-wide Assessment:

- The concentrations of TP and TN concentrations generally increased from the headwaters to the outlet for all event types (snowmelt, rainfall, base flow) averaged for the 6-yr study.
- The western tributary had higher dissolved nutrient concentrations than the central tributary and IFC mainstem.
- Areas of reduced flow, such as dammed water bodies, caused a reduction in TSS by sedimentation.

Nutrient Water Quality Sub-index:

- Years with lower flow tended to have higher NWQS-I scores (i.e., better water quality).
- The 6-yr average NWQS-I scores decreased from upstream to downstream on the mainstem. The average score of the furthest upstream (headwaters) was in the fair category; whereas, all the other stations were in the poor category.
- Tributaries generally had lower index scores (i.e., poorer water quality) compared to most mainstem index scores.

Comparison to the AESA Watersheds:

- The 6-yr median FWMCs of TP and TN at the outlet of IFC were 3- and 1.6-fold greater, respectively, than the medians for the 23 watersheds used in the AESA Water Quality Program from 1999 to 2006.
- The IFC Watershed was rated as a moderate intensity agriculture watershed, and the TN and TP concentrations for the watershed were between values obtained for the moderate and high agriculture intensity AESA watersheds.

Synoptic Surveys:

- The low-flow synoptic survey was considered base flow (i.e., groundwater discharge) as there was not active runoff from the landscape. The high-flow survey captured the effects of a rainfall event, which resulted in increased flow in IFC. Flow during the high-flow synoptic survey was within the typical range of average flows for the month of May.
- The average flow among the mainstem sites was more than 100-fold greater during high-flow compared to low-flow conditions. The average flow for the tributary sites was 220-fold greater during high-flow compared low-flow conditions.
- The contribution from the monitored tributaries to flow in the mainstem was of a higher proportion during low-flow compared to high-flow conditions.

- The concentration of water quality parameters was much higher during the high-flow synoptic survey compared to the low-flow synoptic survey. On average, concentration was 2.9-fold greater for TN, nine-fold greater for TP, 25-fold greater for TSS, and 92-fold greater for *E. coli* during the high flow compared to low flow.
- The increase in water quality parameters from low- to high-flow conditions was less in the upper headwaters of the watershed. This suggests that less agriculture activity, and thus less land disturbances in the headwaters, had a larger capacity to buffer against higher nutrient and sediment loss during higher flow.

Streambed Sediment:

- The concentration of STP in sediment samples was low, with an average of 10 mg kg^{-1}. The PSI values were relatively high, ranging from 124 to 509 mg kg^{-1} and DPS values were low, ranging from 0.5 to 17%, with most samples less than 5%. These results suggest that sediment in the drainage channels is not a major source of P in terms of desorption into the water column.
- The few higher DPS values were associated with smaller, more vegetative drainage channels impacted by agricultural activity, compared to the larger, more defined creek channels. The vegetative cover in small channels may have trapped sediment and accumulated plant residue material and caused a modest accumulation on P. The mainstem and larger tributaries were scoured and flushed by larger flows, and this likely prevented the accumulation of sediment saturated with P.

3.5 Impoundment Site

3.5.1 Introduction and Hypotheses

The IMP site was a pasture area used for cattle grazing, and where cattle had direct access to IFC and a tributary of IFC. On the tributary, a constructed earth dam formed a small body of water, or the IMP lake, within the pasture area. Water from the dam outlet continued a short distance down the tributary and entered IFC. Livestock were generally present from May to October and had direct access to the IMP lake. As a result, the shore area of the IMP lake was highly degraded.

The BMPs implemented included exclusion of cattle from the IMP lake using fencing and off-streaming water. The off-stream watering, as well as other cattle distribution techniques (portable windbreak and cattle oiler), were used to encourage cattle to spend less time in the riparian area along the tributary in the IMP pasture. The post-BMP period began when cattle were introduced in mid-June 2009. In addition to BMPs, bioengineering techniques were applied along the shore of the IMP lake.

These BMPs were chosen based on the underlying assumption that cattle with direct access to the IMP lake would contribute nutrients and bacteria to the water. It was also assumed that riparian degradation caused by cattle would enhance sediment and nutrient loss through rainfall and snowmelt runoff, and that fecal pats in the riparian area would contribute to nutrients and bacteria during runoff events. The hypotheses were:

- The exclusion of cattle from the IMP lake would improve the riparian area (i.e., more plant growth with greater diversity and less bare ground) along the shoreline of the lake, and in turn, reduce the amount of nutrients (N and P), sediment, and bacteria entering the lake.
  - Particulate nutrients are expected to be reduced more than dissolved nutrients because of reduced erosion potential along the lake shore. Bacteria will be reduced by preventing the deposition of fresh fecal pats along the shore area and in the lake.
- The use of off-streaming watering, a cattle oiler, and salt blocks will cause cattle to spend less time at the tributary and improve the riparian area along the tributary.

3.5.2 Methods

3.5.2.1 Site Description and Management

The IMP site was in the far northern part of the IFC Watershed (Figure 3.3). The site included 35 ha of pasture land (IMP pasture), through which portions of IFC and its most westerly tributary flowed (Figure 3.38a). Within the pasture area, an earthen dam was built across the tributary creating a small impoundment of water (IMP lake). The tributary entered the south end of the IMP lake, and when the water in the lake reached a certain level, the water exited through a culvert in the earthen dam at the north end and continued to flow in the tributary and into IFC. The surface area of the IMP lake was about 0.9 ha in size. The tributary leading to the IMP lake extended south and the total drainage area was about 1387 ha in size (Figure 3.38b). The land use in the southern part of the drainage area was mainly perennial forage and pasture, the northern part was mainly annual crops, and one dairy farm existed in the drainage area.

The IMP site was within the CTN6/U1h soil landscape model as described by the Agricultural Region of Alberta Soil Inventory Database (AGRASID) (Alberta Soil Information Centre 2013). Soils within this model are Orthic Black Chernozems and include dominant (60% or more) Cowley soil series and significant (10 to 30%) Beazer and Standoff-XT soil series, with well drained characteristics. The landform in the model is described as undulating, high relief, with a limiting slope of 4%, and parent material consisting of fine-textured water-laid sediment and medium textured till.

During the study, the pasture was rented to one or two producers each year for cattle grazing (Table 3.15), and was generally managed in the same manner as previous years. One of the renting producers rotated cattle between the IMP site and adjacent pasture land owned by the producer. Occasionally, in addition to the IMP pasture, cattle also had access to adjacent cropland (Fields A and B; Figure 3.38) during the fall grazing period. Field A was 7 ha in size and Field B was 88 ha in size. When cold weather and snow cover prevented the cattle from grazing in January and February 2010, the herd was fed bales of grass-mixed hay.

In 2012, due to a change in land ownership, the IMP pasture was converted to annual crop land and the fence around the IMP lake was removed. In early April 2012, a double-disc implement was used to till the pasture and prepare the land for seeding. The width of the uncultivated area that remained around the IMP lake ranged from 0.5 to 11 m. In mid-April, the former pasture and Fields A and B were seeded to canola (*Brassica napus* L.) using a seeding rate of 5.6 kg ha^{-1}. Fertilizer was placed with the seed at a rate of 252 kg ha^{-1} of 46-0-0, 190 kg ha^{-1} of 9-11-11-23, and 1.12 kg ha^{-1} of boron. No manure was applied. Because the canola was glyphosate tolerant, glyphosate was used for in-crop weed control during the growing season at a rate of 2.5 L ha^{-1}.

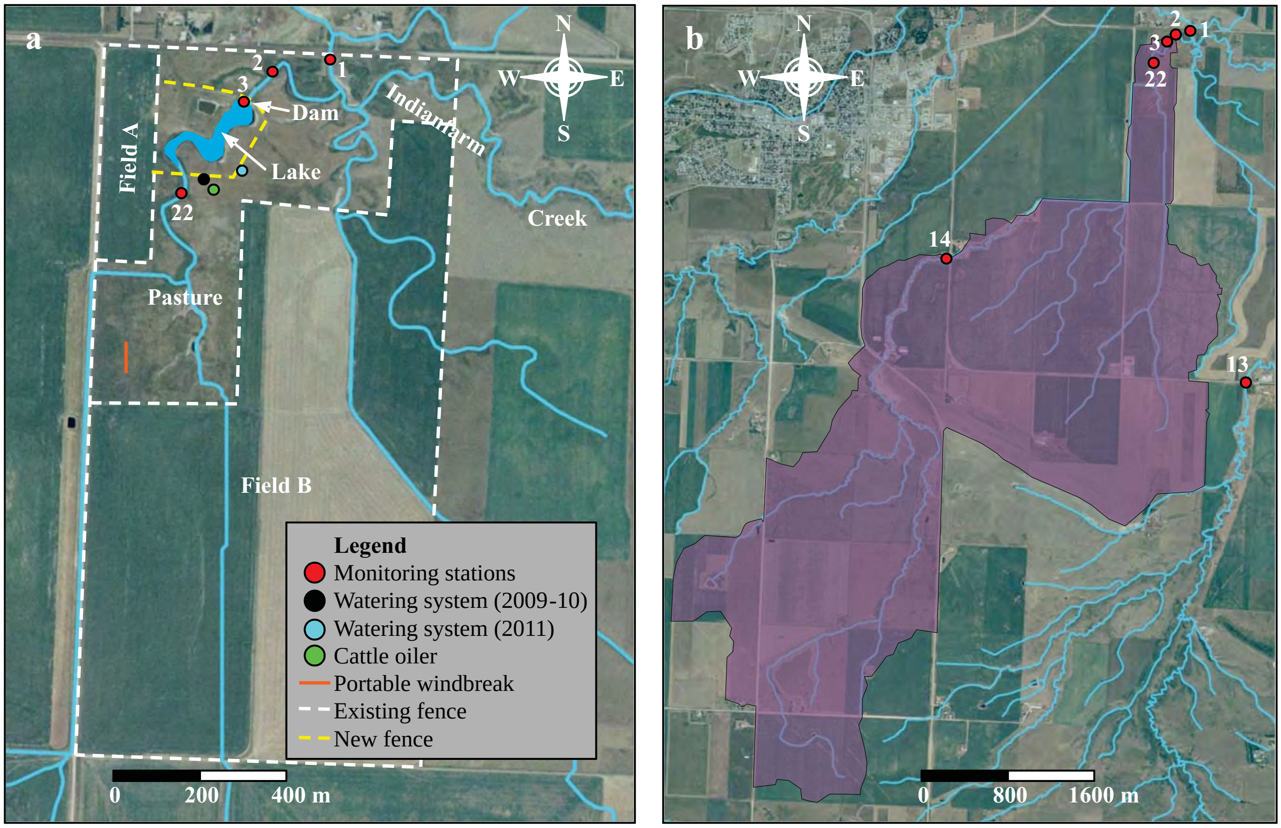

Figure 3.38. The Impoundment site showing (a) the pasture area, fencing around the lake, portable off-stream watering system, windbreak, cattle oiler, and water monitoring stations; and (b) the total drainage area of the Impoundment lake.

3.5.2.2 Implementation of Beneficial Management Practices

The BMP plan consisted of excluding cattle from the IMP lake and using cattle distribution tools to detract cattle away from the tributary. A fence was constructed around the IMP lake in November 2008 for the purpose of excluding cattle from the shoreline of the lake. The fenced area was about 4.2 ha in size, including the lake (Figure 3.38a). Therefore, the total grazing area that remained in the IMP pasture was about 31 ha.

Table 3.15. Impoundment site grazing schedule during the pre (2007 and 2008) and post (2009 to 2011) beneficial management practices periods.

Dates on site[z]	Livestock[y]	Area grazed[x]	Number of days on site
	2008		
Early to late Jul	80 cc	pasture and lake[w]	~21
Mid-Sep to late Oct	80 cc	pasture and lake[w]	~35
	2009		
Jun 15 to Jul17	80 cc	pasture	32
Aug 22 to Sep 7	80 cc	pasture	16
	2010		
Dec 20 to Feb 26	200 cows	pasture, Fields A and B	69
Jun 25 to Jul 2	84 cc, 2 bulls	pasture	8
Jul 3 to 11	84 cc, 3 bulls, 14 heifers	pasture	9
Jul 24 to Aug 8	84 cc, 3 bulls, 14 heifers	pasture	16
Sep 14 to 17	84 cc, 3 bulls, 14 heifers	pasture, Field A	4
Oct 21 to 29	84 cc, 3 bulls, 14 heifers	pasture	9
Nov 7 to 13	84 cc, 3 bulls, 14 heifers	pasture	7
Nov 14 to 19	84 cc, 3 bulls, 14 heifers	pasture, lake[v]	6
	2011		
Jun 22 to Jul 22	87 cc, 2 bulls	pasture	30
Aug 18 to Aug 21	87 cc, 21 heifers	pasture, lake[v]	3
Sep 17 to Sep 19	87 cc, 21 heifers	pasture, lake[v]	2
Oct 22 to Oct 30	87 cc, 21 heifers	pasture, Fields A and B	8
Nov 14 to Jan 13[u]	235 cows	pasture, Fields A and B	60

[z] Cattle grazing activity in 2007 was not recorded, but it was likely similar to 2008.
[y] cc = cow-calf pairs.
[x] Size of grazing areas: pasture = 31 ha, Field A = 7 ha, and Field B = 88 ha.
[w] Prior to BMP implementation cattle were not restricted from the Impoundment lake.
[v] The fenced enclosure around the Impoundment lake was opened to allow cattle to graze for short periods.
[u] Estimated removal date.

Distribution tools used included a solar-powered, portable watering system, cattle oiler, and portable windbreak. The watering system (Kelln Solar Water System, Lumsden, Saskatchewan) consisted of a 1900-L plastic trough, 64-watt solar panel, battery, control panel, and 24-volt K2 float pump. Water was pumped through an above-ground, 4.5-cm PVC pipe from the IMP lake. The watering system was first installed along the south section of the new fence in June 2009 prior to the grazing season (Table 3.15). The watering trough remained in the same location in 2010 and was relocated along the east portion of the fence in 2011. The watering system was removed from the site and stored during the winter months.

In August 2009, the pump failed due to a faulty seal and the pump was replaced. This same failure also occurred in September 2010. On June 9, 2011, the pump was placed in a vertical PVC pipe to keep aquatic weeds away from the pump intake (Figure 3.39). The tube had a vertical slot cut about 15 cm wide for most of the length of the tube. The purpose of the cut was to allow the discharge hose to move vertically with the level of the water. The vertical slot was covered with two strips of thin hose material to allow the discharge hose to move vertically, yet keep sunlight out so not to encourage aquatic weed growth within the PVC pipe (Figure 3.39a). Holes were drilled in the upper three-quarters of the pipe to allow water to flow through. The vertical pipe was secured in the IMP lake by inserting the bottom of the pipe into the lake sediment (Figure 3.39b). A steel lid was fastened to the top of the PVC pipe. Because of previous pump failures, the pump was replaced with a new pump of the same model type in 2011. Also in 2011, the electrical wires between the pump and the solar power unit were placed inside a PVC pipe to protect from chewing by animals (e.g., muskrat).

The portable watering system was used during the spring-to-fall grazing period. The 200 cows from December 2009 to February 2010 and the 235 cows from November 2011 to January 2012 did not have access to the portable water system. These animals obtained water from the tributary, IFC, a small dugout in the southern part of the IMP pasture, and a watering system at the far south end of Field B.

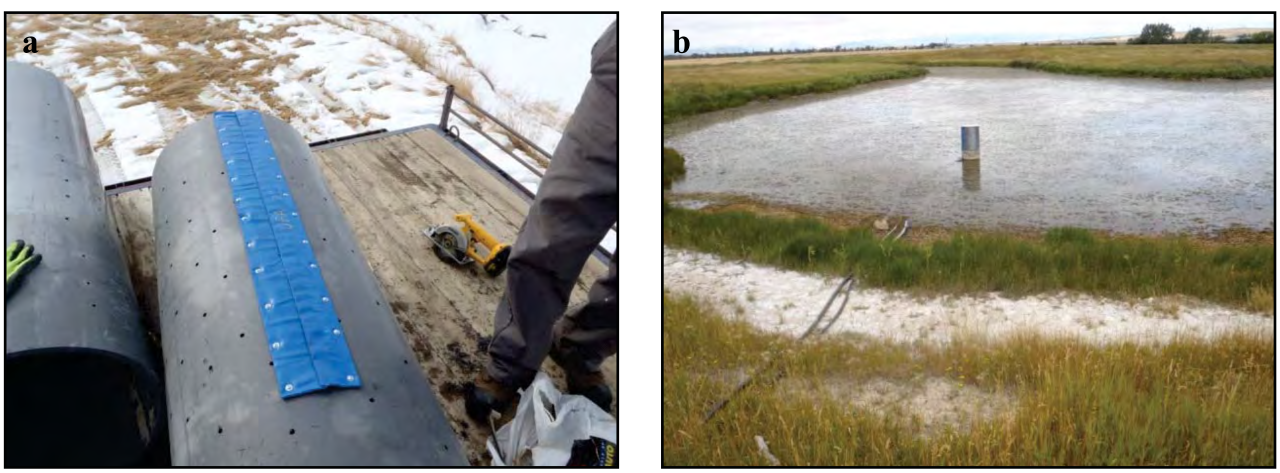

Figure 3.39. The PVC pipe used to house the water pump showing the (a) covered vertical slot and (b) its deployment in the Impoundment lake.

In 2010, a cattle oiler (single upright model; Lewis Cattle Oiler Co. Ltd., Oak Lake, Manitoba) and a portable windbreak (2.6 m high by 9.3 m long, wood on a steel frame) were added to the site. The cattle oiler also had a container for salt blocks or minerals.

The grazing schedule was not modified during the BMP period, and the rotation of cattle in and out of the pasture followed the normal schedules used by the producers (Table 3.15). The cattle were generally not in the pasture during April and June, when riparian areas are more susceptible to degradation. During the BMP period, for the most part, cattle were not allowed inside the fenced area around the IMP lake in order to protect the water and promote vegetation recovery. However, cattle were allowed to graze within the fenced area for 6 d in November 2010, 3 d in August 2011, and 2 d in September 2011 (Table 3.15). Light grazing for short periods can promote healthy biodiversity by increasing the chance of survival for some species (West 1993).

3.5.2.3 Riparian Quality

The Alberta Riparian Habitat Management Society (i.e., Cows and Fish) was contracted to conduct visual riparian health assessments at the IMP site on June 13, 2007 and on June 13, 2012 (Sub-section 2.11.1). Both sides of the channel were surveyed, from IFX1S to IFX1N (Figure 3.40), encompassing the perimeter of the IMP lake. The distance surveyed along the channel was about 0.7 km, and the width of the riparian zone ranged from 4 to 10 m, with an average of 7 m. The total riparian area surveyed was about 0.49 ha.

In addition to the Cows and Fish surveys, annual transect surveys were carried out from 2008 to 2012. In 2008, five paired transects (Transects 1 to 5) were surveyed on either side of the IMP lake (Figure 3.40). Two additional transects were added in 2009: one downstream of the IMP lake outlet on the tributary (Transect 7), and the other on IFC about 75 m upstream from the outlet of the tributary (Transect 6). The number of transects surveyed varied from year to year (Table 3.16); however, only the first year and last year data are presented in this report. To assess BMP effects within the fenced area around the IMP lake, Transects 1 to 5 were compared between 2008 and 2012. To assess BMP effects outside of the fenced area, Transects 6 and 7 were compared between 2009 and 2012. Transects 6 and 7 were surveyed at the start of the BMP period in 2009 and were assumed to represent pre-BMP conditions. Further details about the riparian transect surveys, including statistical analyses of changes in riparian community composition, species richness (SR), effective Shannon diversity (ED), and evenness (E), are provided in Sub-section 2.11.2.

To assess whether riparian communities as a whole differed before and after BMP implementation, two-way PERMANOVA statistical tests (Sub-section 2.11.2) were performed on the species percent cover data from plots in the respective transects for the fenced (Transects 1 to 5) and non-fenced (Transects 6 and 7) areas. Because these transects often included two different vegetation zones (i.e., riparian and transition), zone was used as a blocking variable, and thus changes within each zone were assessed as opposed to the whole transect. In addition to this analysis, species richness (SR), evenness (E), and effective Shannon's diversity (ED) were also calculated for each plot and the differences between zone and year were assessed using an ANOVA-style approach (Sub-section 2.11.2).

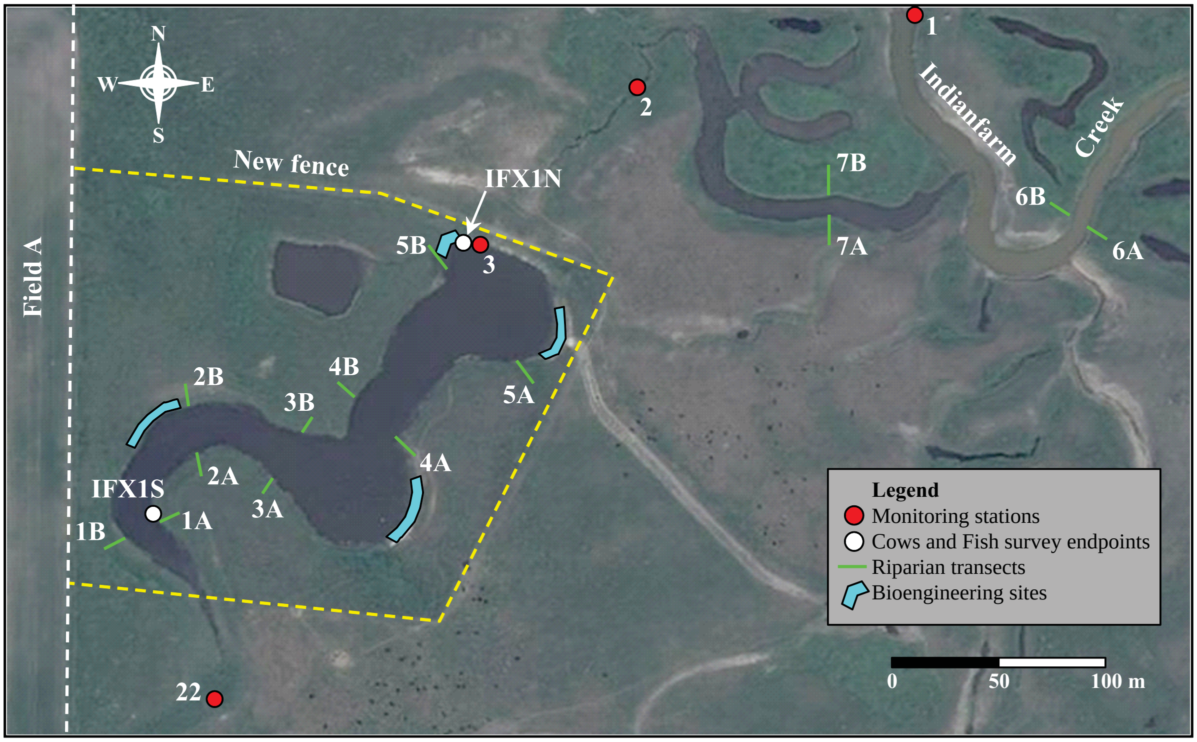

Figure 3.40. Location of the Cows and Fish survey endpoints, riparian transects, bioengineering sites, and water monitoring stations at the Impoundment site.

Table 3.16. Riparian transect surveys carried out at the Impoundment site from 2008 to 2012.

Survey date	Transects surveyed[z]
June 6, 2008[y]	1, 2, 3, 4, 5
June 12, 2009	2, 4, 6, 7
June 11, 2010	1, 3, 5
June 23, 2011	2, 4
July 6, 2012	1, 2, 3, 4, 5, 6, 7

[z] Each transect consisted of two parts (a and b), one on either side of the Impoundment lake or channel.
[y] Transects 6 and 7 were not surveyed in 2008.

3.5.2.4 Bioengineering

Bioengineering was carried out to promote recovery of the riparian zone along the IMP lake during the post-BMP period. Live willow stakes were planted along the IMP lake shoreline in 2009 and 2011. In 2009, sandbar willows (*Salix exigua* Nutt.) were collected from along IFC on March 1. The willows were 1 to 2 cm in diameter and 1 to 1.5 m long. These stakes were stored in cold water (about 0°C) until planting. Approximately 900 stakes were planted at four locations along the IMP lake (Figure 3.40) on May 13, 2009. The locations were chosen based on evidence of erosion and shoreline slumping. Metal rods and shovels were used to create holes in the soil, into which at least half the lengths of the willow stakes were inserted. The soil was then packed around the stakes to ensure good contact.

Because of poor survival of the live stakes planted in 2009, another 437 sandbar willow cuttings were planted along the banks at the same four locations in 2011. New willow stakes were harvested at the recommended minimum diameter size of 2.5 cm or larger on April 13, 2011 from along the Oldman River (Figure 3.41a). The stakes were stored in water at 0°C until they were planted on May 6, 2011 (Figure 3.41b). These stakes were planted three-quarters of the length into the ground.

Survival counts were completed on August 31, 2009, September 1, 2010, September 13, 2011, and July 18, 2012. Photo reference points were established and photos were taken for visual comparisons.

Figure 3.41. Bioengineering procedures showing (a) harvesting willows along the Oldman River on April 13, 2011, and (b) planting willows along the Impoundment lake on May 6, 2011.

3.5.2.5 Water Flow and Quality

There were three monitoring stations at the IMP site: Stations 2, 3, and 22 (Figures 3.1 and 3.40). Water samples were collected at all three stations and flow was measured at Station 2, which was about 75 m downstream from the dam outlet and Station 3 in the IMP lake. After 2008, water sampling was discontinued at Station 2, since the water quality data in 2007 and 2008 were similar ($r^2 \geq 0.9$) between Stations 2 and 3 (data not shown). Station 2 was kept to measure flow from the IMP lake. However, due to high flows in spring 2010, the flume at Station 2 was dislodged and the float potentiometer did not function properly. The flume was not repaired due to severe channel erosion and flow was estimated using a staff gauge at Station 3 for the remainder of 2010. Flow was not calculated in 2011 and 2012. Station 22 was added upstream of the IMP lake in April 2009 to collect grab samples.

Snowmelt and rainfall runoff processes affected flow exiting the IMP lake, but since this site was near the end of a tributary of IFC, there were also base flow events when no observed overland flow affected the IMP area. There were also periods when no flow occurred through the culvert in the earthen dam. Water samples were thus collected during four different types of flow events at the IMP site, and were classified as a snowmelt, rainfall, base flow, or impoundment sample. Base flow samples were taken when there was no active snowmelt or rainfall, yet water flowed through the outlet of the dam. An impoundment event was when water did not flow through the outlet of the dam.

The pre-BMP period included water quality data collected from March 2007 to mid-June 2009. The post-BMP period began when cattle entered the IMP pasture on June 15, 2009. There were not enough pre-BMP data from Station 22 to make pre- and post-BMP comparisons between Stations 3 and 22. Therefore, annual averages were used to compare water quality data between these two stations. General statistical analysis used for water quality data is described in Sub-section 2.8.4.

3.5.3 Results and Discussion

3.5.3.1 Implementation of Beneficial Management Practices

The fencing of the IMP lake and the off-stream watering system worked well. The cattle immediately began to use the watering system when it was first introduced in 2009, even though they still had access to the tributary and IFC during the post-BMP period. Cattle trails to the water trough and oiler were evidence of frequent use (Figure 3.42). The livestock owner observed that the cattle preferred drinking from the water trough than from IFC or the tributary, and overall, the owner was pleased with the off-stream watering system.

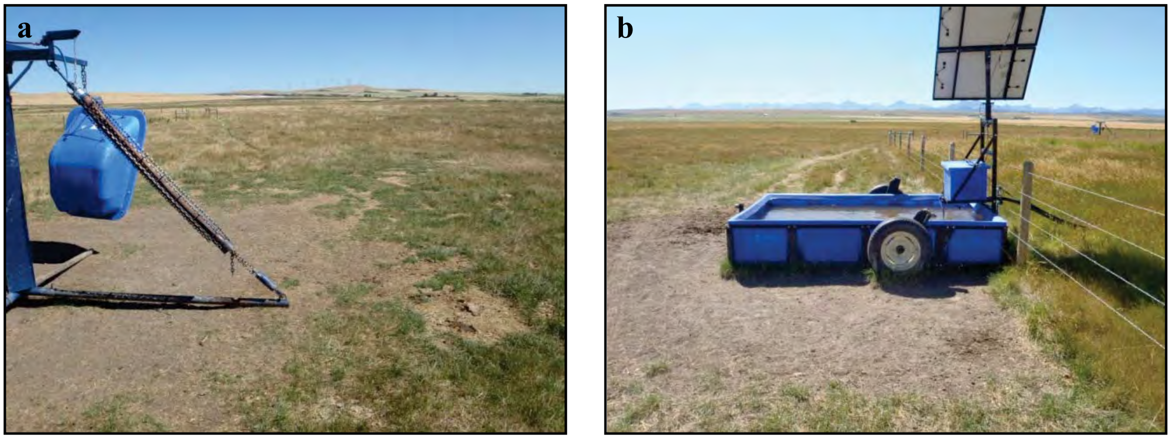

Figure 3.42. Evidence of frequent cattle use shown by trails leading to the (a) cattle oiler and (b) water trough. Images taken on August 24, 2011.

The cattle distribution tools (off-stream water trough, oiler, and windbreak) were successful at attracting cattle, which likely meant that cattle spent less time in the riparian areas of IFC and its tributary. Others have shown that these types of distribution tools can help reduce cattle access to, and movement towards, natural water sources, and reduce nutrient transport to surface water (Agouridis et al. 2005; Miller et al. 2010). However, the congregation of cattle at these distribution tools caused changes to the local pasture. It was observed that areas devoid of vegetation (i.e., dead areas) were created at the water trough, oiler, and wind break (Figure 3.43). The degree of disturbance of these areas, or piospheres, tend to be greatest near the point of attraction and the impact becomes less with distance from the centre (Washington-Allen et al. 2004), and this was observed at the IMP site. These localized impacts can affect vegetation, soil erosion, and soil chemistry.

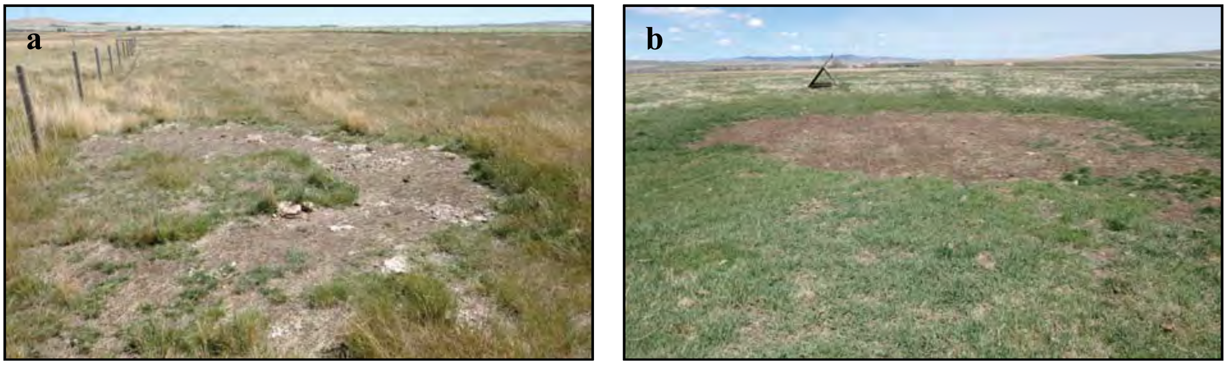

Figure 3.43. Dead areas caused by cattle at previous locations of the (a) water trough and (b) wind break in the Impoundment pasture. Images were taken on August 24 and May 18, 2011, respectively.

The shift in cattle distribution from the creek to the distribution tools may have resulted in a concurrent shift in nutrient distribution via a spatial change in the deposition of cattle feces and urine. This has been documented by Miller et al. (2010), who found that soil NO_3-N concentration was seven times higher and STP concentration was three times higher ≤ 5 m from three off-stream water troughs compared to ≥10 m from the troughs.

During each post-BMP year, the water trough, oiler, and windbreak were moved to a new location each spring. Moving the tools more frequently may have reduced the severity of the piospheres. Also, more frequent repositioning of the tools may have enticed the cattle to graze the underutilized areas of the pasture. However, in terms of pasture quality, there is a tradeoff between the number of impacted piospheres, and the degree of their degradation. Smaller distribution tools such as mineral licks and salt blocks can be conveniently moved more frequently. However, larger tools such as portable windbreaks, water troughs, and oilers require more effort to move. Also, relocating a portable water system will require repositioning the pipeline from the water source and the pipe length may have to vary.

As indicated above, the cattle owners were pleased with the off-stream watering system. However, the watering system did fail several times and required repairs. During these times, the only source of water for the cattle was from the tributary and IFC. Additional management was required to check mechanical watering systems on a regular basis, but this was not critical for the IMP site as the cattle had access to an alternative water source. For producers using off-stream watering at sites without access to alternative water, they will need to be vigilant in checking watering systems.

The cost of the BMPs implemented at the IMP site was nearly $18,000 (Table 3.17). The majority (74%) of this cost was for the fence and off-stream watering system, and this was largely a one-time expense for establishment of the BMPs. Most of the equipment could have been used for several more years. Additional routine costs would include maintenance of the oiler and repairs to the watering system, but at this particular site, the distribution tools were no longer needed because of a change in land use described above. These tools could either be re-deployed elsewhere or sold.

The IMP pasture was converted to annual crop land and the fence around the IMP lake was removed (Figure 3.44). Because of this change in land use, the post-BMP period ended in early April 2012 when the pasture area was tilled. Water samples collected after the land conversion in 2012 were considered to reflect the new land cover conditions.

Table 3.17. Cost of beneficial management practices at the Impoundment site.

Year	Item	Cost ($)	Labour (h)
2008	fence supplies	800	
	fence construction	5,000	
	Kellin solar water system	7,450	8
	Sub-total	**13,250**	**8**
2009	bioengineering[z]	425	10
	BMP maintenance and management	-	6
	Sub-total	**425**	**16**
2010	cattle oiler	3,012	
	portable windbreak	1,250	
	BMP maintenance and management	-	4
	Sub-total	**4,262**	**4**
2011	BMP maintenance	-	4
	Sub-total	-	**4**
	Grand total	**17,937**	**32**

[z] Refer to Sub-section 3.5.2.4 for details about the bioengineering.

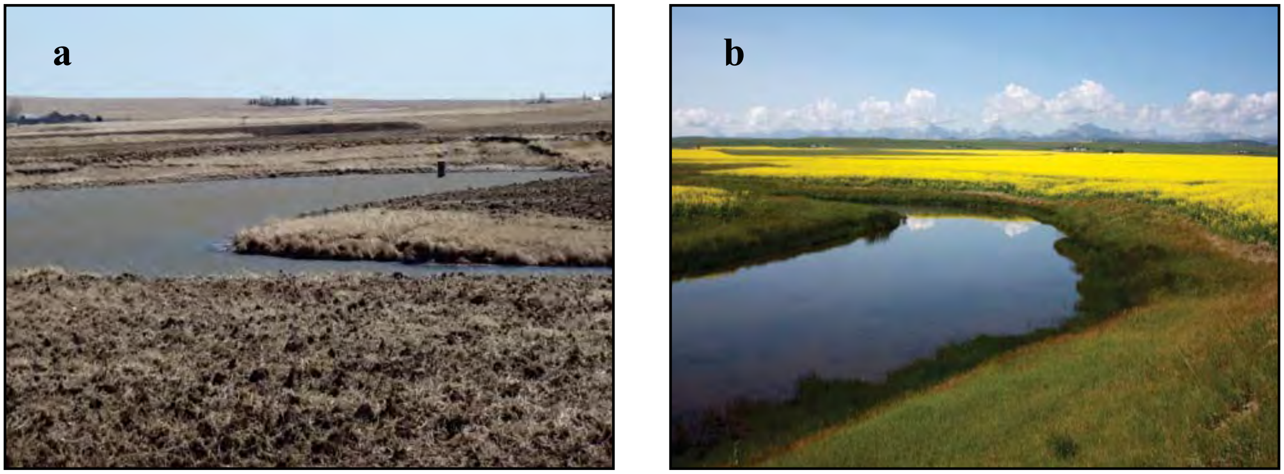

Figure 3.44. The Impoundment pasture was (a) tilled with a double disc in early April 2012 and (b) then used to grow canola as shown on July 6, 2012.

3.5.3.2 Riparian Quality

Cows and Fish assessment. Riparian quality improved at the IMP lake from 2007 to 2012. The overall riparian health rating increased from 38 to 57%, suggesting a positive effect of greater precipitation in the post-BMP years (Sub-section 3.2), and possibly by the implemented BMPs (Table 3.18). Overall improvement was observed for the vegetation and soil/hydrology factors. The 2012 survey showed the riparian area was well vegetated overall, undesirable species remained prevalent, and preferred woody plant communities were becoming established through bioengineering. It was noted that restricting direct livestock access to the IMP lake reduced soil compaction and bare ground exposure around the edge of the water body. Even with the increased health rating, the riparian area was still rated as unhealthy (i.e., <60%) in 2012. The 2012 evaluation placed the IMP site below the provincial average of 69%, which is based on the assessment of 2059 riparian health inventory sites on 330 water bodies in Alberta from 1997 to 2010.

Table 3.18. Summary of the Cows and Fish riparian health assessment carried out at the Impoundment (IMP) site on June 13, 2007 and June 13, 2012.

	2007 assessment			2012 assessment			
	IMP site	Max. score	Rating (%)[z,y]	IMP site	Max. score	Rating (%)[z,y]	Health difference
Vegetation							
Vegetative cover of site	6	6		6	6		no change
Invasive plant species (cover)	1	3		1	3		no change
Invasive plant species (density distribution)	0	3		0	3		no change
Disturbance-caused undesirable herbaceous species	0	3		0	3		no change
Preferred tree and shrub establishment and regeneration	0	6		6	6		improved
Utilisation of preferred trees and shrubs	3	3		2	3		declined
Live woody vegetation removal by other than browsing	na[x]	na		3	3		na
Human alteration of site vegetation	0	6		0	6		no change
Vegetation rating	10	30	33	18	33	55	improved
Soil/hydrology							
Human alteration of site physical structure	0	12		4	12		improved
Severity of human-caused alterations to physical site	0	3		2	3		improved
Human-caused bare ground	4	6		6	6		improved
Degree of artificial removal/addition of water	9	9		6	9		no change[w]
Soil/hydrology rating	13	30	43	18	30	60	improved
Overall rating	23	60	38	36	63	57	improved

[z] Site score as a percentage of the maximum possible score.

[y] Healthy (80 to100%): Little or no impairment to riparian functions.
Healthy but with problems (60 to 79%): Some impairment to riparian functions due to human or natural causes.
Unhealthy (<60%): Impairment to many riparian functions due to human or natural causes.

[x] na = not applicable.

[w] The dam and its overflow structure were present for the 2007 inventory, but the 2007 score for the removal and addition of water did not reflect the artificially high water levels. The score was lowered in the 2012 inventory because the dam kept water levels high and decreased fluctuation, and the lowered score more accurately reflects the health of the wetland. The health trend was 'no change' because the site itself had not changed even though the score had.

Transect assessment. For plots adjacent to the IMP lake (Transects 1 to 5), a one-way PERMANOVA test showed that overall, communities were significantly different in at least two year-zone combinations. Pairwise comparisons between groups showed that communities were significantly different between 2008 and 2012 in the riparian and transition zones (Table 3.19). For Transects 6 and 7, communities were not significantly different between 2009 and 2012 in either zone. For riparian plots at the IMP lake, community differences were mostly attributable to (in order of importance from most to least, for those species whose contribution to overall difference was greater than 4%) an increase in the percent cover of Baltic rush (*Juncus balticus*), a decrease in sedge (*Carex spp.*), an increase in Kentucky bluegrass (*Poa pratensis*), a decrease in quackgrass (*Agropyron repens*), increases in alkali grass (*Puccinellia*) and wild mint (*Mentha arvensis*), and a decrease in spike rush (*Eleocharis spp.*). Species differences are shown in Appendix 5. For transition plots at the IMP lake, community differences were mostly attributable to an increase in Kentucky bluegrass; decreases in quackgrass, smooth brome (*Bromus inermis*), and spike rush; and increases in bentgrass (*Agrostis spp.*), western snowberry (*Symphoricarpos occidentalis*), and crested wheatgrass (*Agropyron cristatum*).

For Transects 6 and 7, although not statistically significant, differences in riparian plots between 2009 and 2012 were mostly attributable to decreases in western snowberry and smooth brome, an

Table 3.19. Analysis of differences in the overall plant communities (percent cover) between year (i.e., before and after BMP implementation) and vegetation zone combinations at the Impoundment site. [z]

Overall model			
Source	Sum of squares	F value	*P* value
	Transects 1 to 5 (impoundment lake)		
Year×Zone	26.2	8.253	0.0001
Total	33.57		
	Transects 6 and 7 (tributary and IFC)		
Year×Zone	4.431	2.057	0.0022
Total	5.87		

Differences between Year×Zone combinations
Bonferroni-corrected *P* values

	2008 Riparian	2008 Transition	2012 Riparian	2012 Transition
Transects 1 to 5 (impoundment lake)				
2008 Riparian	-	0.001	0.023	0.001
2008 Transition		-	0.001	0.001
2012 Riparian			-	0.001
2012 Transition				-

	2009 Riparian	2009 Transition	2012 Riparian	2012 Transition
Transects 6 and 7 (tributary and IFC)				
2009 Riparian	-	0.829	0.188	0.068
2009 Transition		-	0.432	0.133
2012 Riparian			-	0.107
2012 Transition				-

[z] One-way PERMANOVA statistical test .

increase in wild strawberry (*Fragaria virginiana*), a decrease in sedge, increases in willow (*Salix spp.*) and yarrow (*Achillea millefolium*), and a decrease in Kentucky bluegrass. Differences in the transition plots for Transects 6 and 7, although not statistically significant, were mostly attributable to an increase in western snowberry; a decrease in smooth brome; and an increase in Kentucky bluegrass, wild strawberry, and western wheatgrass (*Agropyron smithii*). The increases in wild strawberry, willow, and yarrow, and the decreases in smooth brome and Kentucky bluegrass were considered positive changes.

For Transects 1 to 5, the average (least squares mean) SR and ED were significantly greater in 2012 than in 2008 (Table 3.20). Evenness was also significantly different between years, with the higher mean in 2008 rather than in 2012. These three measures were not significantly different between zones. For Transects 6 and 7, all three measures were not significantly different between years (Table 3.20), though all were greater in 2012 than in 2009. For these transects, SR and ED were significantly different between zones; whereas, E was not. In all of the above analyses, the interaction between zone and year was not significant, and was thus removed from the model.

The SR and ED significantly increased from 2008 to 2012 in the riparian area at the IMP lake (Table 4.20) and a total of 23 species not identified in 2008 were observed in 2012. It is important to note that cultivation around the IMP lake occurred in the spring of 2012, and this may have led to the increase in species found in 2012. Cultivation created bare soil areas within and adjacent to parts of the riparian area and likely this provided an opportunity for disturbance-related species to grow. However, SR and ED did not increase significantly in Transects 6 and 7, implying that the fencing out of cattle may have contributed to the increases observed in the IMP transects. It should also be considered that there may simply have been greater differences between 2008 and 2012 for Transects 1 to 5 than between 2009 and 2012 for Transects 6 and 7. Additionally, Transects 6 and 7 had greater SR and ED than the IMP sites before and after BMP implementation, perhaps implying that the IMP sites were initially more degraded, and thus had more potential for colonization by species that were already present at Transects 6 and 7. Furthermore, Transects 6 and 7 were located on a tributary of IFC and the mainstem itself, as opposed to the lake area, and these areas may have had different plant habitat, and thus, species composition. Because of these differences, direct comparisons between the IMP lake transects (Transects 1 to 5) and Transects 6 and 7 cannot easily be made.

Although SR and ED have been emphasized so far, it is of even greater importance to consider whether grazing reduces native species diversity and whether these species are being replaced by introduced or upland species (Belsky et al. 1999). Reductions in native riparian or aquatic species are nearly always viewed as negative, or as representing declining ecosystem health (Ohmart 1996). In this study, riparian transects increased in desirable and undesirable (non-native) species and in biodiversity; however, this was often more related to the increase in undesirable species. It is hard to assess whether this represents a positive change, but it is worth recalling that despite an increase in undesirable as well as desirable species, Cows and Fish showed the overall vegetation rating to improve for this site. Although an improvement was indicated, we cannot rule out that weather variation may have played a part.

Some of the changes in vegetation cover before and after BMP implementation in the fenced-off area can be considered reflective of improvements in riparian health. For instance, the increases in *J. balticus* in the riparian zone, and *S. occidentalis* in the transition zone, represented an increase in bank-stabilizing vegetation. The presence of *Salix spp.* (sandbar willow), which was the result of live-stakes planted in 2009 and 2011 as part of the bioengineering effort, was also positive. *Salix spp.* is a highly desirable riparian species because it provides food and shelter for wildlife and livestock, and its root system can spread within the riparian zone and provide stability (Hale et al. 2005). Other shrub species surveyed in 2012 but not 2008 were *Elaeagnus commutata* (wolf willow) and *Rosa acicularis* (prickly wild rose). These are also desirable riparian shrub species that contribute to plant diversity and provide food and habitat for wildlife. The decrease in *A. repens* in the riparian and transition zones, and decrease in *B. inermis* in the transition zone, were also an improvement as these are considered to be weeds associated with disturbance. However, other invaders, such as *P. pratensis*, increased in both zones. Additionally, other disturbance-related species were observed in 2012, including crested wheatgrass, *Hordeum jubatum* (foxtail barley), *Medicago lupulina* (black medic), *Phleum pratense* (timothy), and *Tragopogon dubius* (goat's beard). These species were present in or near bare soil, and may be associated with the cultivation activity that occurred at the site in spring 2012. Invasive species are likely to continue to persist unless managed directly and by promoting the establishment and regeneration of native wetland species. The IMP riparian area is possibly in a state of ecological succession and may require further time to contain more desirable species that are typical of a riparian area. A return or partial return to desirable native species is preferred from an ecological perspective. This goal is also desirable for future grazing potential for a recovered area. However, even the establishment of undesirable species in the short term on degraded and eroded areas likely provides some water quality benefits, in that any improved vegetation cover may enhance bank stability and filtration of runoff.

Table 3.20. Type 3 test results of fixed effects (y ear, zone) in the analysis of species richness (SR), effective diversity (ED), and evenness (E) at the Impoundment site.[z] Values shown are least squares means.

	Transects 1 to 5[y]				Transects 6 and 7[y]			
Effect[x]		SR	ED	E		SR	ED	E
Year[w]	2008	3.3*a*	2.3*a*	0.77*b*	2009	7.2*a*	4.9*a*	0.72*a*
	2012	6.4*b*	3.8*b*	0.63*a*	2012	8.1*a*	6.4*a*	0.79*a*
Zone	Riparian	4.7*a*	3.0*a*	0.70*a*	Riparian	9.1*b*	6.7*b*	0.77*a*
	Transition	4.4*a*	2.9*a*	0.69*a*	Transition	6.2*a*	4.6*a*	0.74*a*

[z] Generalized linear model (with a Poisson error distribution and log link function) used rather than a general linear model.
[y] Means within year or zone followed by the same letter are not significantly different ($P < 0.1$).
[x] Year × zone interaction was not significant.
[w] 2008 and 2009 = pre-BMP, 2012 = post-BMP.

3.5.3.3 Bioengineering

Of the original 900 willows that were planted in May 2009, only 20% survived to August 2009, and 7% to September 2010. The poor survival of these stakes was likely a result of their small diameters, which were less than the recommended minimum size of 2.5 cm. In contrast, of the 437 willow live stakes planted in May 2011, which had larger diameters, 223 (51%) survived to July 2012 (Figure 3.45). This survival rate may seem low, but 15 to 25% survival can be considered successful in a dry ecoregion (personal communication, Tim Romanow, Executive Director, Milk River Watershed Council Canada).

3.5.3.4 Water Flow and Quality

Water flow. Throughout the study, the total annual flow from the IMP lake varied considerably, and was dominated by different sources. In 2008 and 2010, the majority of the flow generated was from rainfall runoff; whereas, in 2007 and 2009, flow was mostly the result of snowmelt. Notably, the annual flow in 2010 was 645,015 m^3 yr^{-1}, which was three- to ten-fold higher than the annual flows from 2007 to 2009 (Figure 3.46). Flow was not measured in 2011 and 2012 because of the failure of Station 2. However, based on the watershed outlet monitoring station, the annual flow from the IMP lake in 2011 was likely similar to the 2010 flow. The 2012 flow was likely much less than in 2010 or 2011, and was probably similar to, or less than, the flow in 2007.

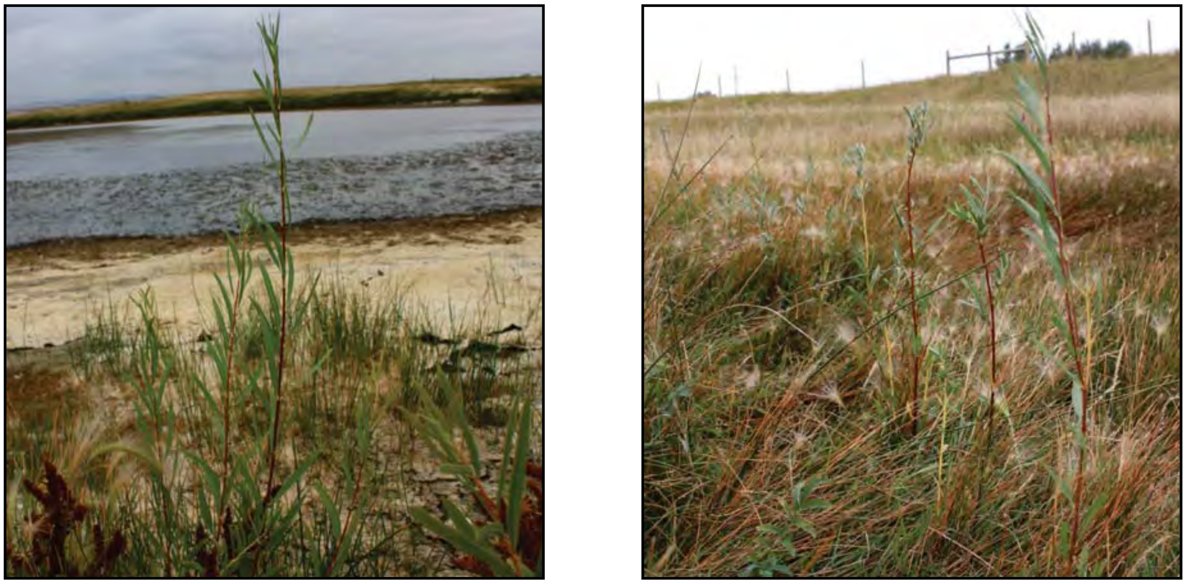

Figure 3.45. Images of willows growing at the Impoundment site in September 2011.

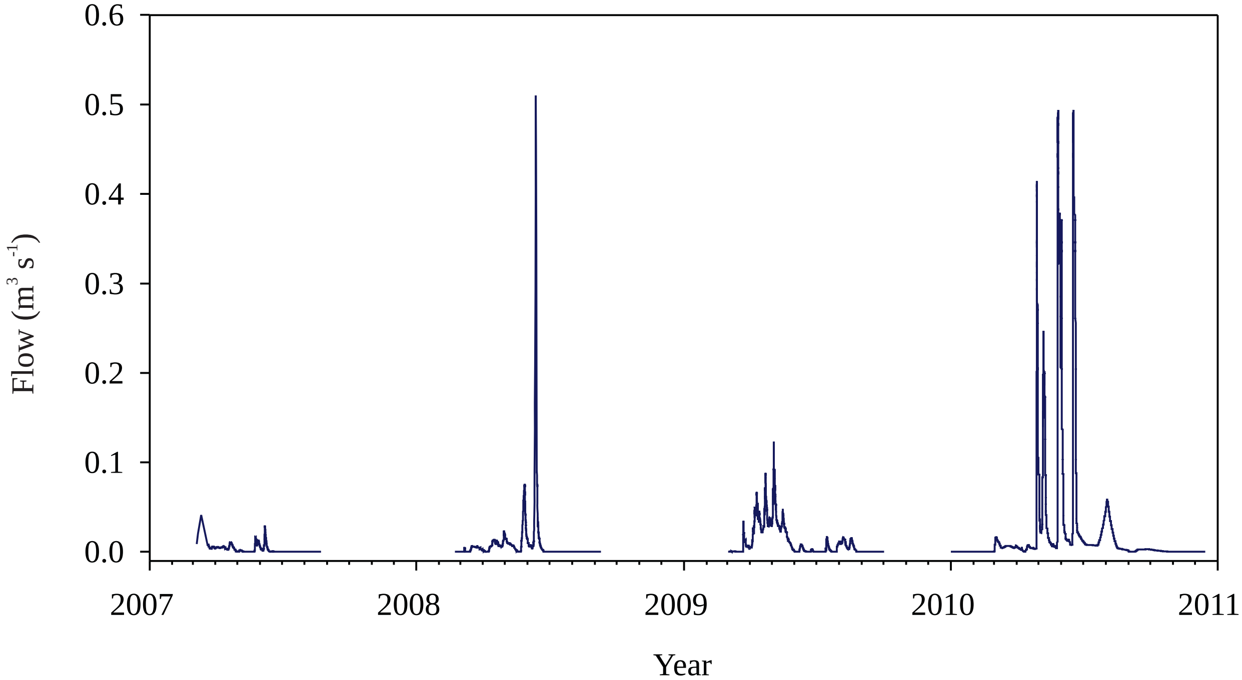

Figure 3.46. Hydrograph for Station 2 from 2007 to 2010. Flow at this site was not monitored in 2011 and 2012.

General water quality observations. Water quality at Station 3 always met the 100 mg L^{-1} NO_3-N + NO_2-N guideline for livestock use. The highest TN concentrations occurred in April or May and ranged from 9.6 to 47.5 mg L^{-1} (Figure 3.47a). Most of the N in the IMP lake was in the organic form, except in 2010 and 2011, which were also the wettest years of the study. In these two years, TN was greater, and dissolved inorganic N was the major fraction, a pattern that was also observed at other sites in IFC (Sub-section 3.4.2). Ammonia N concentration was highest in snowmelt runoff and IMP samples, and accounted for less than 10% of TN. Peak TP concentrations generally occurred within the first 3 mo of each year (Figure 3.47b). Total dissolved P accounted for 49 to 82% of TP from 2009 to 2012 (Table 3.21). Concentrations of N and P parameters were generally highest in 2011 compared to the other years, except for PP at Station 3 in 2012 (Table 3.21).

Similar to NH_3-N, the concentration of Cl was higher in the IMP samples when runoff did not occur. Chloride concentration was lowest in the spring, increased during the year, peaked in the winter, and then decreased again in the following spring (Figure 3.47d).

The average EC values at Station 3 were highest in 2007 and 2012 (Table 3.21), which were also the driest years during the study (Sub-section 3.2). Linking this result to precipitation is tenuous, because 2010, which had the highest precipitation, did not have the lowest average EC value. Lower average EC values occurred in 2009 and 2011, which were preceded by years that had greater than 30-yr average precipitation (Sub-section 3.2).

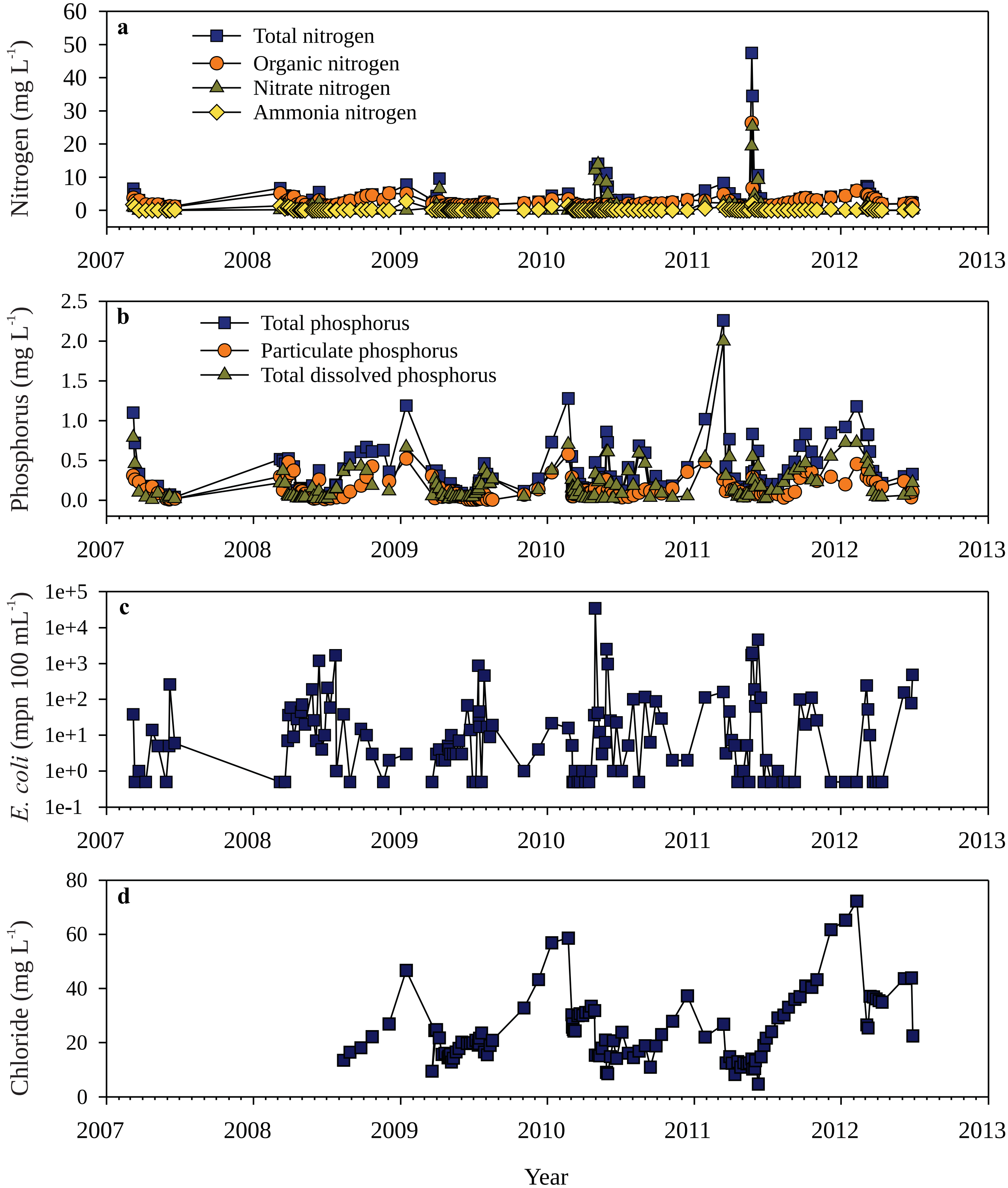

Figure 3.47. Concentrations of (a) total nitrogen, organic nitrogen, nitrate nitrogen, and ammonia nitrogen; (b) total phosphorus, total dissolved phosphorus, and particulate phosphorus; (c) *Escherichia coli (E. coli)*; and (d) chloride measured at the water monitoring Station 3 in the Impoundment lake from 2007 to 2012.

Table 3.21. Average annual runoff water quality parameters measured upstream (Station 22) and downstream (Station 3) at the Impoundment site.[z]

Station	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	*E. coli*	EC	pH
		(mg L^{-1})								(mpn 100 mL^{-1})	(µS cm^{-1})	
2007 (snowmelt n=9, rainfall n=7, base flow n=1)												
Downstream	9	2.61	2.04	0.22	0.33	0.32	0.18	0.14	31	36	1266	8.48
Upstream[y]	0	na	na	na	na	na	na	na	na	na	na	na
Difference	na	na	na	na	na	na	na	na	na	na	na	na
2008 (snowmelt n=9, rainfall n=7, base flow n=1)												
Downstream	16	2.92	2.20	0.51	0.22	0.25	0.08	0.17	60	128	1111	8.29
Upstream[y]	0	na	na	na	na	na	na	na	na	na	na	na
Difference	na	na	na	na	na	na	na	na	na	na	na	na
2009 (snowmelt n=9, rainfall n=7, base flow n=1)[x]												
Downstream	17	2.11	1.61	0.43	0.03	0.18	0.13	0.05	17	38	749	8.80
Upstream	17	1.88	1.54	0.28	0.03	0.17	0.14	0.03	4	7963	886	8.39
Difference[w]		*0.23*	*0.07*	*0.15*	*0*	*0.01*	*-0.01*	*0.02*	*13*	*-7925*	*-137*	*0.41*
2010 (snowmelt n=10, rainfall n=12, base flow n=4)[x]												
Downstream	26	3.59	1.31	2.10	0.13	0.28	0.17	0.11	20	1470	963	8.28
Upstream	26	2.74	1.06	1.53	0.12	0.24	0.17	0.08	15	746	1051	8.15
Difference		*0.85*	*0.25*	*0.57*	*0.01*	*0.04*	*0*	*0.03*	*5*	*714*	*-88*	*0.13*
2011 (snowmelt n=7, rainfall n=9, base flow n=2)[x]												
Downstream	18	7.61	3.21	3.99	0.35	0.42	0.29	0.13	43	495	692	8.10
Upstream	18	9.28	3.15	5.67	0.38	0.38	0.25	0.13	63	236	733	8.12
Difference		*-1.67*	*0.06*	*-1.68*	*-0.03*	*0.04*	*0.04*	*0*	*-20*	*259*	*-41*	*-0.02*
2012 (snowmelt n=5, rainfall n=1, base flow n=2)[x]												
Downstream	8	4.11	3.22	0.62	0.27	0.43	0.21	0.22	32	48	1201	8.16
Upstream	8	2.37	1.74	0.49	0.14	0.28	0.20	0.08	10	77	1202	7.99
Difference		*1.74*	*1.48*	*0.13*	*0.13*	*0.15*	*0.01*	*0.14*	*22*	*-29*	*-1*	*0.17*

[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, pH = potential hydrogen.
[y] Station 22 was added in 2009.
[x] Number of pairings between Stations 3 and 22 by event type in parentheses for each year.
[w] A negative difference indicates a decrease in water quality parameter concentration from upstream (Station 22) to downstream (Station 3).

The vast majority of samples (84%) collected at Station 3 contained less than 100 mpn 100 mL^{-1} *E. coli*, and about 5% of samples had values greater than 1000 mpn 100 mL^{-1} *E. coli* (Figure 3.47c). The three highest *E. coli* peaks occurred during rainfall runoff on April 30, 2010 (34,480 mpn 100 mL^{-1}), on June 9, 2011 (4611 mpn 100 mL^{-1}), and on May 28, 2010 (2500 mpn 100 mL^{-1}). The cause of the very high *E. coli* concentration in April 2010 is unknown. On the same date, the concentration of *E. coli* was 10,760 mpn 100 mL^{-1} near the inlet to the IMP lake (Station 22). Geese and ducks were observed on the IMP lake that day and may have been the source for *E. coli*.

Water fowl were observed on the lake on other occasions (Figure 3.48). However, a detailed survey of the number and frequency of geese, or other water fowl, on the IMP lake was not recorded. It is possible that yearly fluctuations of geese populations on the IMP lake may affect the variability of some water quality parameters, including *E. coli*. In the absence of a detailed survey, we assume that the influence of water fowl on the IMP lake was generally consistent from year to year.

The other biological parameter that was measured, chlorophyll *a*, tended to be highest in the winter months (Figure 3.49). The highest chlorophyll *a* concentrations occurred in December 2008, February 2010, and March 2012.

Generally, most water quality parameters increased in concentration from upstream (Station 22) to downstream (Station 3) at the IMP site from 2009 to 2012 (Table 3.21). The exceptions were EC in all years, *E. coli* in 2009 and 2012, TN and NO_3-N in 2011, NH_3-N in 2009 and 2011, PP and TSS in 2011, and TDP in 2010. Many of the exceptions occurred in 2011.

Figure 3.48. Geese on the frozen Impoundment lake on March 14, 2009.

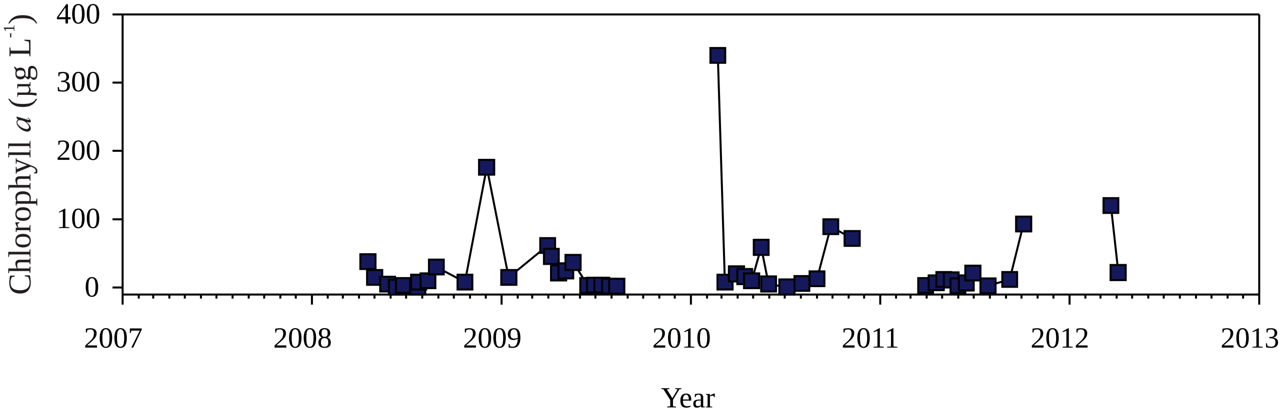

Figure 3.49. Concentration of chlorophyll *a* measured at the water monitoring Station 3 in the Impoundment lake from 2007 to 2012.

BMP effects on water quality. For all events combined, most water quality parameters did not differ between the pre- and post-BMP periods at Station 3. However, TP and TDP were significantly greater in the post-BMP period than in the pre-BMP period (P<0.1), by 31 and 71%, respectively (Table 3.22). This finding was consistent when separating flow events into snowmelt, rainfall, and base flow events, although concentrations of TP and TDP were not significantly different in impoundment samples between the pre- and post-BMP periods. The higher concentration of these two parameters in the post-BMP period as compared to the pre-BMP period was most prevalent for rainfall events, followed by base flow events, and then by snowmelt events. For example, TP concentration was higher by 131% for rainfall, 118% for base flow, 59% for snowmelt, and 38% for impoundment (Table 3.22). Additionally, when considering different types of flow events, NO_3-N was greater in post-BMP during snowmelt and NH_3-N was greater in post-BMP during rainfall. Other parameters (NO_3-N, NH_3-N, TDP, and *E. coli*) had relatively higher concentrations in the post-BMP period, but were not significantly different from the pre-BMP period (Table 3.22). However, when the two active runoff event types (snowmelt and rainfall) were combined, the average concentrations of ON, NO_3-N, NH_3-N, TP, and TDP were significantly higher in the post-BMP period and TSS and EC were significantly lower in the post-BMP period (Table 3.22). Total N and *E. coli* were higher in the post-BMP period, but were not significantly different from the pre-BMP period.

Table 3.22. Average runoff water quality parameters measured at Station 3 at the Impoundment site in the pre-BMP and post-BMP periods.[z]

Event	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	*E. coli*	EC	pH
		(mg L^{-1})								(mpn 100 mL^{-1})	(µS cm^{-1})	
						Snowmelt						
Pre-BMP[y,x]	26	3.00	2.14	0.59*b*	0.26	0.29*b*	0.13*b*	0.16	54*a*	14	1036	8.35*a*
Post-BMP	23	3.12	2.09	0.75*a*	0.25	0.46*a*	0.28*a*	0.18	25*b*	29	926	8.01*b*
						Rainfall						
Pre-BMP	6	2.32	1.58	0.69	0.03*b*	0.13*b*	0.07*b*	0.06	12	280	1020	8.40
Post-BMP	32	6.28	2.39	3.62	0.21*a*	0.30*a*	0.22*a*	0.08	28	1529	817	8.61
						Base flow						
Pre-BMP	5	1.70	1.62	0.04	0.03	0.11*b*	0.04*b*	0.07	16	7	1068	8.57
Post-BMP	18	1.82	1.69	0.08	0.03	0.24*a*	0.15*a*	0.10	18	19	933	8.83
						Impoundment						
Pre-BMP[x]	17	3.16	2.80	0.03	0.30	0.39	0.21	0.16	33	121	913*b*	9.16
Post-BMP	18	3.21	2.95	0.03	0.23	0.54	0.31	0.23	33	26	1256*a*	8.88
						Active runoff (snowmelt plus rainfall)						
Pre-BMP	32	2.87	2.03*b*	0.61*b*	0.22*b*	0.26*b*	0.12*b*	0.14	46*a*	71	1033*a*	8.36
Post-BMP	55	4.96	2.27*a*	2.42*a*	0.23*a*	0.37*a*	0.25*a*	0.12	27*b*	902	863*b*	8.36
						All events						
Pre-BMP[x]	54	2.85	2.24	0.37	0.23	0.29*b*	0.14*b*	0.14	39	82	1000	8.62*a*
Post-BMP	91	3.99	2.29	1.48	0.19	0.38*a*	0.24*a*	0.14	26	554	954	8.55*b*

[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, pH = potential hydrogen.
[y] Average BMP period concentrations per parameter followed by letters are significantly different at P < 0.10.
[x] n values shown are maximums. The n value may be less due to missing data.

These results largely imply that the BMPs implemented did not improve water quality at this site. However, TSS concentration during snowmelt and active runoff was significantly reduced after BMP implementation (Table 3.22), reflecting a possible improvement caused by cattle exclusion from the IMP lake. In contrast though, most parameter concentrations were higher in the post-BMP period compared to the pre-BMP period. One of the likely reasons why improvements in water quality were generally not detected was that the comparison of the pre- and post-BMP periods, shown in Table 3.22, was only performed on data from Station 3, which was near the outlet of the IMP lake. Station 3 could be viewed as an outlet site for the whole sub-basin that drained to this point. The sub-basin was 1387 ha in size, with a tributary system of several kilometres in length (Figure 3.38b). The 4 ha excluded from cattle around the IMP lake represented only 0.3%, of the total area of the sub-basin, and the last 700 m of the drainage system. Annual flow was on average higher during the post-BMP period, and considering the relatively small size of the BMP area compared to the total drainage area to Station 3, potential effects by the BMP's were likely masked by other effects on water quality in the whole sub-basin.

3.5.4 Conclusions

- The BMP plan of cattle exclusion and off-stream watering was successfully implemented at the IMP site. The fenced area around the IMP lake successfully excluded cattle from accessing the lake, but also provided the opportunity to allow controlled grazing within the fenced area for short periods without adversely affecting the riparian area around the lake.
- Field observations showed that cattle preferred to drink from the off-stream watering system rather than from the creek. By using the off-stream watering system, along with the cattle oiler and windbreak, the cattle likely spent less time in the riparian area that was not excluded.
- The use of the off-stream water system, cattle oiler, and windbreak by the cattle caused highly disturbed areas around these tools. There is a tradeoff of sacrificing a few areas within the pasture by not moving these tools or moving the tools frequently and having more, but less disturbed areas. The latter, as well as checking and maintaining equipment, would require additional management time.
- The overall Cows and Fish riparian health rating increased from 38 to 57%, suggesting a positive effect of greater precipitation in the post-BMP years, and possibly by the implemented BMPs. The 2012 survey showed the riparian area was well vegetated overall, undesirable species remained prevalent, and preferred woody plant communities were becoming established through bioengineering. Also, the restricted direct livestock access to the IMP lake reduced soil compaction and bare ground exposure around the edge of the water body.

- The riparian vegetation transect assessment showed an increase in desirable and undesirable species, and in biodiversity, in the post-BMP period. However, this increase in species was often more related to the increase in undesirable species.
- The bioengineering was successful following a second planting of live stakes in 2011. The study observed that when planting willow stakes in a dry ecoregion, attention to willow stake diameter is crucial to the willow's survival.
- Water quality at Station 3 always met the 100 mg L^{-1} NO_3-N + NO_2-N guidelines for livestock use.
- Water quality parameter concentrations were generally higher at the downstream station compared to the upstream station from 2009 to 2012. The exceptions were EC in all years, *E. coli* in 2009 and 2012, and TN and NO_3-N in 2011.
- The BMPs implemented did not improve water quality at this site. Many parameter concentrations were significantly higher in the post-BMP period compared to the pre-BMP period during active runoff (snowmelt plus rainfall). Potential effects by the BMP's were likely masked by other effects on water quality in the whole sub-basin upstream from the IMP site. The concentration of TSS was significantly reduced after BMP implementation, reflecting a possible improvement caused by cattle exclusion from the IMP lake.

3.6 North Manure Field and Fencing Site

3.6.1 Introduction and Hypotheses

The site was originally selected as a potential manure application BMP site with the expectation that because it was associated with a nearby feedlot, the soil nutrient concentrations would be excessive. However, preliminary soil-test results in fall 2006 showed an average STP concentration of 46 mg kg^{-1}, which was less than the agronomic threshold of 60 mg kg^{-1} (Howard 2006). The lack of excess soil nutrients was because of the relatively in-frequent manure application of once every 5 to 7 yr.

It became apparent, however, that instead of a concern about manure management, fall grazing by cattle was likely a potential risk to water quality at this site. Two BMP sites were established. One BMP site, referred to as the North Manure Field site (NMF), included a grass drainage channel. The BMP plan at this site was to reduce the time cattle spent in the grass channel during fall grazing through cattle distribution management. This site was monitored with an edge-of-field station. The other BMP site was along the perimeter of the larger field where cattle had direct access to IFC, and referred to as the Fencing site (FEN). The BMP applied was exclusion of cattle from the creek using a permanent fence. Hydrologically, the two BMP sites were separate. However, both sites are presented in this sub-section because they occurred in the same field. Specific hypothesis for the NMF site was:

- The implementation of cattle distribution management techniques to reduce access to the in-field grass drainage channel at the NMF will reduce the nutrient and bacteria concentrations in runoff water at the edge-of-field.
  - It is expected that dissolved forms of nutrients will be reduced more than particulate forms.
  - Bacteria may not be a prevalent water quality concern, given that the fall cattle grazing leaves the manure pats exposed to winter conditions. However, a reduction is still expected.

The FEN site could not be assessed for water quality with the monitoring stations that were in place in late 2009, when cattle access to IFC was discovered at this site. The nearest (2.8 km) upstream station on IFC was Station 23 and the nearest (0.6 km) downstream station was Station 12 (Figure 3.4). These distances from the FEN were too far apart to isolate the FEN site. Also, the monitoring of Station 23 started in 2010 and this only provided 1 yr of pre-BMP data. Bioengineering was also carried out at the Wintering site (Sub-section 3.8), a few metres upstream from Station 12, and the outlet of the tributary from the Feedlot site (Sub-section 3.14) entered IFC between the FEN site and Station 23. Effects of the bioengineering and tributary on IFC would have interfered with the assessment of water quality for the FEN site.

3.6.2 Methods

3.6.2.1 Site Description and General Management

The NMF and FEN BMP sites were in a large, single management field the size of six quarter sections (390 ha) in the northern portion of the watershed (Figures 3.3 and 3.4). This site was within the CWY1/U1h and CWY1/U1l soil landscape models as described by the Agricultural Region of Alberta Soil Inventory Database (Alberta Soil Information Centre 2013). The soils in these models are Calcareous and Rego Black Chernozems, and include dominant (60% or more) Cowley soil series and a significant (10 to 30%) Cowley-ZR soil series, with well drained characteristics. The landform in the model is described as either undulating, high relief landform with a limiting slope of 4%, or undulating, low relief landform with a limiting slope of 2%. Parent material consists of fine-textured water-laid sediment with till-like features. The surface soil at the site had a clay texture (21.7% sand, 46.2% clay), pH of 7.1, electrical conductivity of 1.0 dS m^{-1}, 2320 mg kg^{-1} TN, 857 mg kg^{-1} TP, and 6.7% organic matter (Appendix 4).

Historically, the field was used to grow annual cereal crops. During the study, mainly barley (*Hordeum vulgare* L.) was grown for grain or silage (Table 3.23). Seeding occurred in April or May and was carried out in one pass using an air seeder with wide shovels and coil packers. To prevent wind erosion of soil, zero tillage practices were used. Commercial inorganic fertilizer was applied with the seed. Herbicides were applied to control weeds (Table 3.24).

Cattle were often placed in the field to fall graze after harvest. During the study period, fall grazing occurred from 2008 to 2011 (Table 3.23). The cattle obtained water from troughs at the farmstead at the north end of the field (Figure 3.50). The water source was from the local water co-op. Cattle also had access to IFC at the south end of the field when water was in the channel and not frozen.

The NMF BMP site was a drainage area, 42.6 ha in size, in the north-central part of the field (Figure 3.50). The NMF area was drained by a single channel, which had approximately 925 m of permanent grass cover. The channel flowed from east to west and eventually drained into IFC about 350 m west from the edge of the field. Near the west border of the field and on the south side of the farmyard, the channel drained into a dugout (27 by 65 m). A drainage channel continued west from the dugout. The FEN site was along the south perimeter of the field where cattle grazing in the fall had direct access to IFC. This site was a short distance upstream from Station 12 at the Wintering BMP site.

Prior to the start of the study, manure was last applied in spring 2005 at a rate of 56 Mg ha^{-1} (wet weight) to the west and east center quarter sections and in the fall to northwest and northeast quarter sections (Figure 3.50). No manure was applied in the drainage area of Station 4 during the 6-yr study. Manure was applied to the southwest quarter section in March 2009; however, this quarter section was south and not part of the drainage area to Station 4. Manure was applied to the three east quarter sections at a rate of 61 Mg ha^{-1} (wet weight) in November 2012, which was after the monitoring period of the study.

Table 3.23. Agronomic management practices at the North manure Field from 2007 to 2012.

Year	Crop	Seeding date	Harvest date	Yield[z] (Mg ha^{-1})	Fertilizer N	P	K	S	B	Number of grazing cattle	Grazing period
					--------- (kg ha^{-1}) ---------						
2007	barley grain	na[y]	na	na	112	17	17	-	-	na	na
2008	barley silage	na	July	16.8	200	17	17	-	-	100	Dec 1 - 15
2009[x]	barley grain	Apr 14	early Sep	5.27	92	6	6	11	-	224	Nov 3 - 25
2010[y,w]	barley grain	Apr 8	Sep 20	4.84	92	6	6	11	-	200	Nov 12 - 30
2011[v,u]	barley silage	May 20[t]	Sep 20	8.96	119	7	11	11	-	80	Oct 17 - Dec 15[s]
2012[r,q]	canola	Apr 18	Sep 10	3.8	133	9	17	44	1	0	-

[z] Silage yields express on a wet-weight basis.
[y] na = not available.
[x] 280 kg ha^{-1} of 33-5-5-4 fertilizer.
[w] Due to a heavy snow fall, cattle were fed silage and bales in the field after November 16.
[v] Seeding rate of 161 kg ha^{-1}.
[u] 229.6 kg ha^{-1} 46-0-0 plus 106.4 kg ha^{-1} 13-16-13-10 fertilizer.
[t] Due to heavy precipitation, re-seeding was carried out in early July.
[s] Cattle were still in the field on December 15
[r] Seeding rate of 5.6 kg ha^{-1}.
[q] 252.23 kg ha^{-1} of 46-0-0, 190 kg ha^{-1} of 9-11-11-23, and 1.12 kg ha^{-1} boron.

Table 3.24. Herbicides applied at the North Manure Field from 2007 to 2012.

Year	Pre-seeding application	In-crop application
2007	na[z]	na
2008	na	na
2009	na	na
2010	glyphosate	thifensulfuron methyl plus tribenuron methyl mixed with pinoxaden
2011	glyphosate and tribenuron methyl (0.4 L ha^{-1})	thifensulfuron methyl plus tribenuron methyl (29.6 g ha^{-1})
2012	glyphosate and tribenuron methyl (2.5 L ha^{-1})	glyphosate (2.5 L ha^{-1})

[z] na = not available.

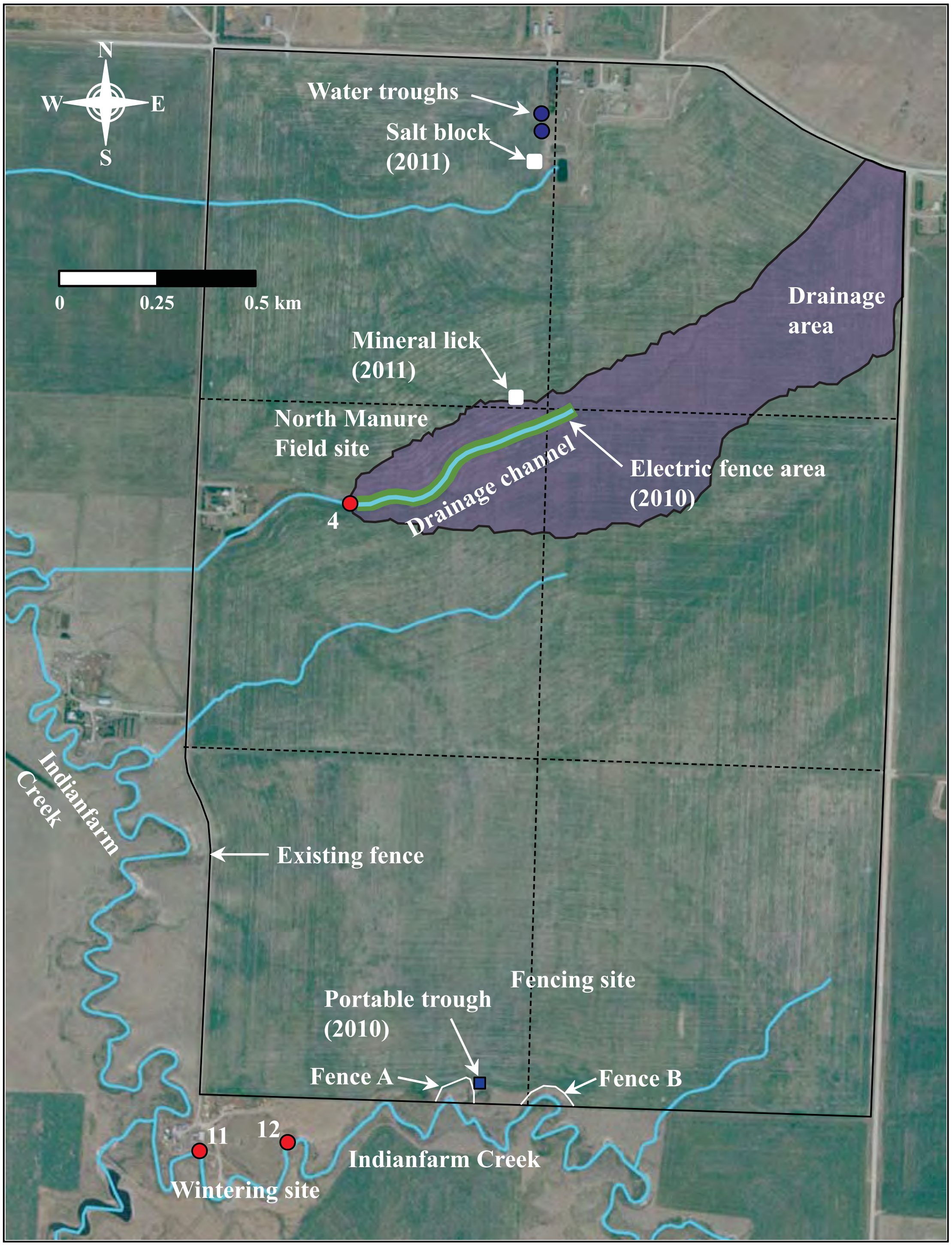

Figure 3.50. The drainage area, drainage channel, Station 4 at the North Manure Field site, and the Fencing site on Indianfarm Creek at the south end of the management area and upstream of Station 12.

3.6.2.2 Implementation of Beneficial Management Practices

As indicated above, two BMP sites were established. The NMF was a small drainage basin within the larger field that was equipped with an edge-of-field monitoring station (Figure 3.50). The FEN site was on IFC at the south edge of the field. The pre-BMP monitoring phase was from 2007 to spring 2010 and the post-BMP phase started in fall 2010 with the implementation of the BMPs and start of the fall grazing season.

NMF site. During the pre-BMP period (2007 to 2010), cattle distribution was monitored and it was determined that cattle lingered the most in the grass channel where the largest density of fecal pats were found (Sub-section 3.6.3.3). In the fall of 2010, an electric fence was erected to exclude the cattle from the grass channel. The fence was solar powered and delivered 2000 volts through two wires. Fiberglass and steel temporary posts were used for the fence. The area fenced was east of Station 4 and was approximately 540 m long by 12 m wide (Figure 3.50). The fence was installed on October 15, 2010 and removed after the cattle were removed at the end of November. In fall 2011, an electric fence was not installed and no other BMP was implemented to limit cattle access to the grass channel. Therefore, a BMP plan was implemented during the 2010 fall grazing season and then discontinued.

The field had two other less prominent drainage channels: one north and the other south of the NMF channel (Figure 3.50). However, these two channels were not in grass and were part of the field. As a result, the cattle were not attracted to these channels.

Fencing site. Prior to the study, the entire field (i.e., six quarter sections) was fenced for the purpose of fall grazing by cattle (Figure 3.50). Along the south perimeter, IFC encroached into the management area at two locations. The BMP adopted was to exclude the cattle from the creek by fencing. On October 12, 2010, two, four-strand barbwire fences (Fences A and B), each about 150 m in length, were constructed at the south end of the field area to prevent cattle access to the creek (Figure 3.50). A portable watering system was temporarily installed near Fence A. This was the same portable watering system used at the IMP site, and a detailed description of this system is in Sub-section 3.5. Shortly after the cattle were placed in the field on November 12, 2010, cold weather developed and the portable watering system did not work well because of the freezing conditions. Also, the watering system experienced problems when it was switched from 12 to 24 volts, which was required to lift water from the creek to the trough. As a result, a portion of Fence B was opened so the cattle could access IFC for water. Therefore, this BMP could not be properly applied in 2010 because of the problems with the water system, and the creek was the only source of water. There was a watering system at the north end of the field; however, this system was not active in fall 2010.

In 2011, Fence B was re-assembled and cattle did not have access to IFC during fall grazing. The portable watering system was not used in 2011 and the water source for the cattle was the water troughs at the north end of the field by the farmyard (Figure 3.50).

Surface runoff from the field flowed into a drainage channel on the south side of Fence A. The upper portion of this channel was subject to sever soil erosion and slumping and was encroaching further north into the field and threatened the integrity of the new fence. In order to control the soil erosion, a retaining wall was constructed at the upper end of the channel (Figure 3.51).

The retaining wall consisted of a centre post (13.3 cm by 13.3 cm by 2.44 m), and two side posts (10.8 cm by 10.8 cm by 1.83 m) (Figure 3.51). These posts were secured approximately 15 cm from the sides of the impacted area. Four treated boards (5.1 cm by 10.2 cm by 2.44 m) were connected horizontally between these posts at the top and bottom. Two sheets of plywood (1.9 cm by 1.22 m by 2.44 m) were secured to the horizontal boards on the side facing the impacted area. Soil was then packed between the plywood and the impacted area. Channeling, constructed from PVC pipe, was placed on the top of the fill soil and down the sides of the retaining wall to contain and redirect runoff into a well vegetated area. A sediment stop above the retaining wall and geo-grid soil stabilizing material below and above the retaining wall were also installed.

In early spring 2011, the retaining wall could not withstand the volume of runoff from the field and the wall sustained damage. The retaining wall was repaired in mid-May 2011 and approximately one week later, the same damage occurred. Fence A remained in place and operational. After discussion with the landowner, the retaining wall was removed in fall 2012.

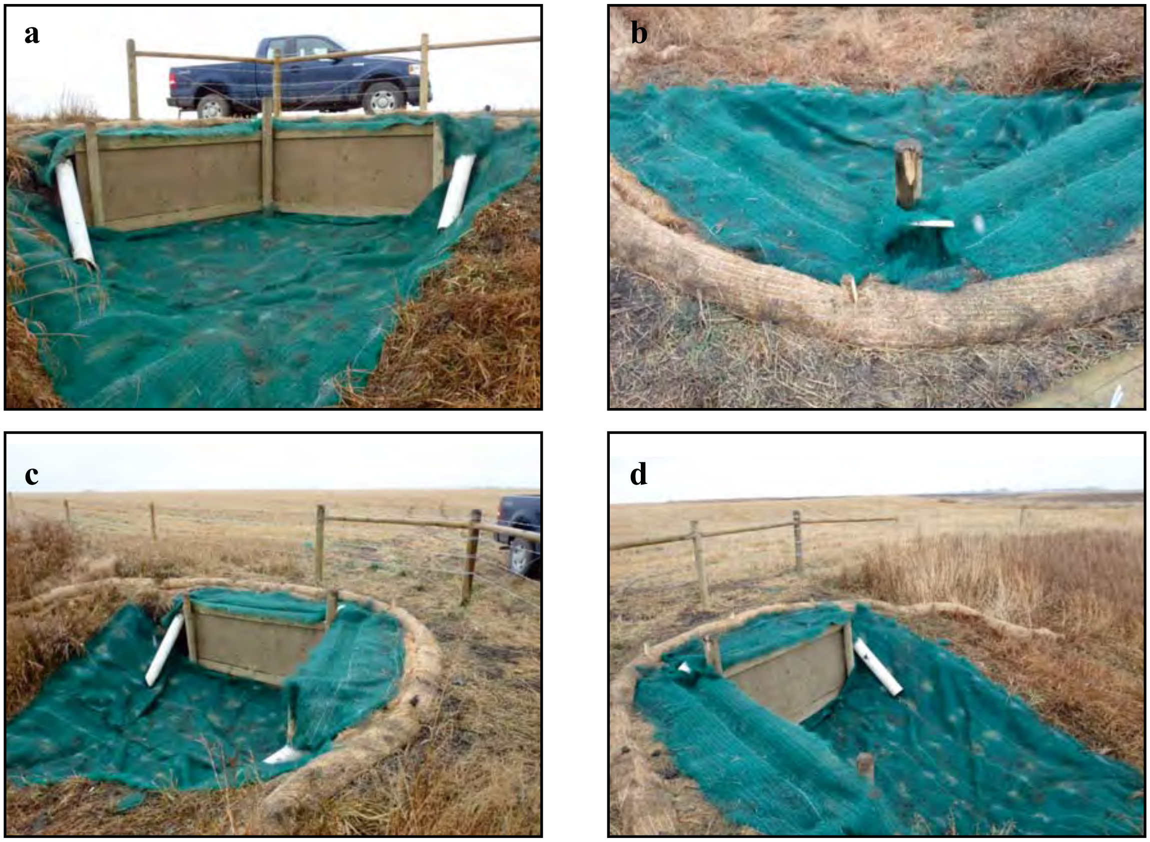

Figure 3.51. Retaining wall constructed in 2010 at the south end of the North Manure Field showing (a) front view facing north, (b) top view facing south, (c) side view facing west, and (d) side view facing east.

3.6.2.3 Soil

Soil characterization samples were collected on October 16, 2008. Agronomic 0- to 15-cm samples were collected at NMF site annually from 2007 to 2012 (Figure 3.52). In spring 2011, agronomic samples were collected twice: before (May 3) and after (June 13) seeding of the crop, which occurred on May 20. Soil-test samples (0 to 60 cm) were sampled only once at this site and these samples were collected in October 2010. Further information about soil sampling is in Subsection 2.9.

Soil samples were also collected from the drainage channel in 2008 to determine whether there was a difference in soil nutrient concentration between the channel and the field. Surface samples (0 to 15 cm) were collected from 13 sample locations at 100-m intervals along the length of the channel. At each sampling point, three to five samples, depending on the channel width, were collected across the channel and a composite sample created.

In fall 2009, samples were collected from the surface 0- to 2.5-cm layer for a more detailed examination of nutrient stratification within the channel. Samples were collected using the frame-excavation method (Nolan et al. 2006, 2007). A steel frame (11 by 60 cm) was driven into the ground until the top of the frame was at ground level and the soil sample was collected from within the frame with a 2.5-cm deep shovel. Samples were collected every 50 m along the grass channel starting 25 m east of Station 4. At each location, three samples were collected across the channel: one sample from the centre of the channel and one sample each from near the two edges of the channel. Eleven locations were sampled for a total of 33 samples.

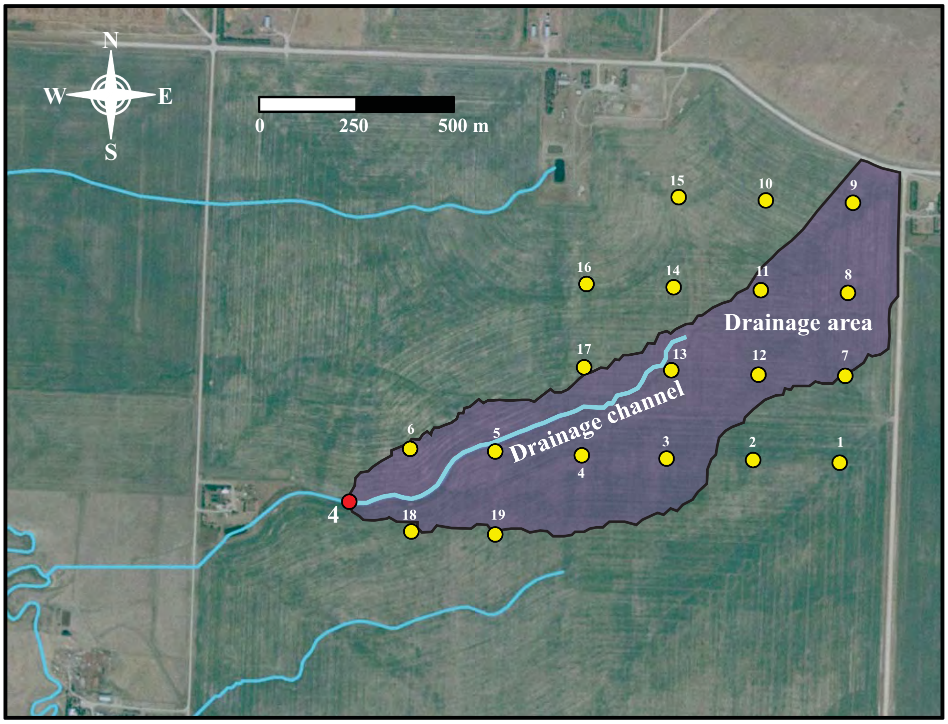

Figure 3.52. Agronomic soil (0 to 15 cm) sampling points at the North Manure Field relative to the drainage area to Station 4.

3.6.2.4 Cattle Distribution

The distribution of cattle grazing in the fall was assessed by two methods: (1) surveying cattle movement within the field during the fall grazing period and (2) measuring fecal pat density. The only successful cattle survey was carried out in fall 2009. Fecal pat density was measured in fall 2009 and fall 2011. A cattle survey and fecal pat counts were not carried out in fall 2010 because of poor weather conditions and snow. A cattle survey was not carried out in 2011 because it was determined that fecal pat density was a better indicator of where cattle congregated.

In 2009, cattle (224 animals) were introduced to the field on November 3 and the survey was carried out on November 4, 5, 9, 12, 16, and 19. Cattle were removed on November 25. Observations began about 30 min prior to sunrise (7:30) and ended about 30 min after sunset (17:00) each survey day. The study area was divided into six quadrants along the quarter section boundaries (Figure 3.53). The location and relative number or percentage of cattle in the six quadrants were noted on data sheet maps every 30 min. A total of 20 counts were taken each day of the survey. The observation points (Figure 3.53) were at a higher elevation and provided a view of all six quadrants. However, with the distance and oblique view, it was difficult to obtain an accurate count of cattle in quadrants A3 and B3 when a large portion of the herd was present at the south end of the field. Based on the recorded observations, the number of cattle per quadrant was estimated for each count. Because of the difficulty in obtaining accurate counts, the total per count usually did not add to 224 animals. Therefore, the number of estimated animals per quadrant was proportionally adjusted so the total equaled 224 animals. Photographs were taken during each observation time to aid in the assessment. Photos of the grass channel were also taken in order to record the changes in this area during the time cattle were present.

Fecal pats were counted at several locations within the management unit using a transect method on November 23, 2009 and November 16, 2011. In 2009, the cattle were removed 2 d after the count. However, in 2011, the cattle were still present in the field 31 d after the fecal pats were counted. The fecal pat count was carried out on November 16 because snow was forecasted. For the fecal pat counts, one transect was located near the centre of each quadrant. In addition, the entire length of the grass channel was assessed extending from Station 4 to the east end of the channel and to the west end of the channel near the farmstead (Figure 3.53). Additional transects were examined in 'hotspot' areas where cattle were observed to spend a longer time than at other areas of the field. Six hotspot areas were identified in 2009 based on the cattle survey and these included areas near water and shelter (Figure 3.53). In 2011, eight hotspot areas were measured, including the six hotspots measured in 2009.

Transects were measured with a 100-m tape measure. The length of the tape was traversed with the mid-point of a 2-m long piece of wood carried above the tape, so that 1-m extended on either side (Figure 3.54). A single, 100-m transect was used at the centre of each quadrant and at each hotspot. Five, 100-m transects and one, 35-m transect were used east of Station 4, and two, 100-m transects and one, 28-m transect were used west of Station 4. The number of fresh fecal pats that appeared within 1 m on either side of the tape was counted. If the fecal pat was partially within the 1-m distance, it was included. Within the grass channel, the tape measure was laid out approximately midway between the drainage channel and the edge of the grass. In the other areas, the tape was laid out in the stubble. One person walked along the tape and counted the fecal pats

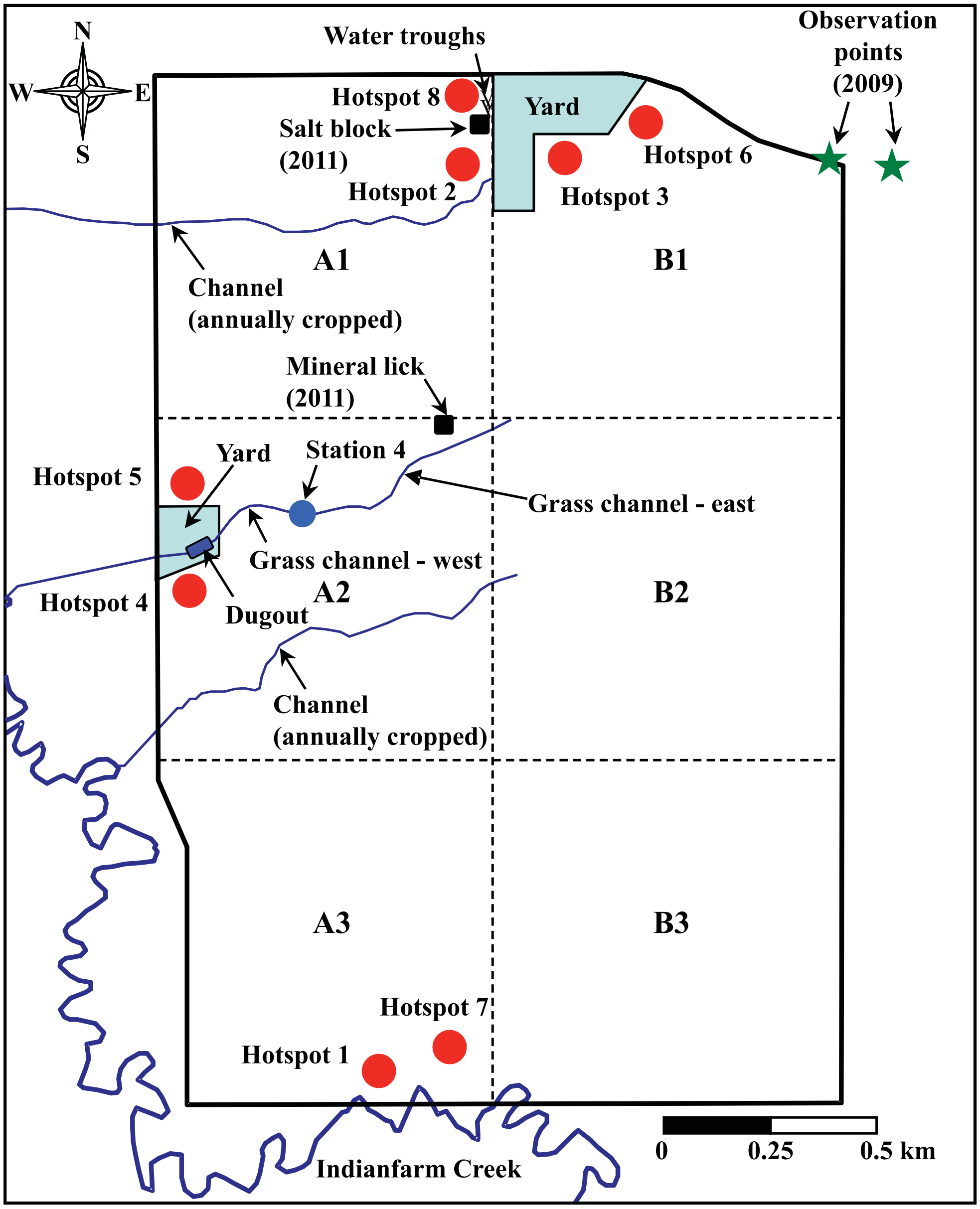

Figure 3.53. Map showing quadrants, water monitoring Station 4, and hotspots.

and a second person recorded the numbers (Figure 3.54). Counts were converted to a density and expressed as pats per hectare.

Statistical analysis of the cattle survey values was carried out using SAS version 9.2 (SAS Institute Inc. 2008). For the cattle survey values, averages of the six quadrants were tested using the Least Squares Means test in the Mixed procedure with variance components as the variance structure and the repeated and pdiff options. For the fecal pat density values, the four groups of transects (east channel, west channel, hotspots, quadrant centres) were tested using the Least Squares Means test in the Mixed procedure with variance components as the variance structure and the repeated and pdiff options. A significance level of $P < 0.1$ was used.

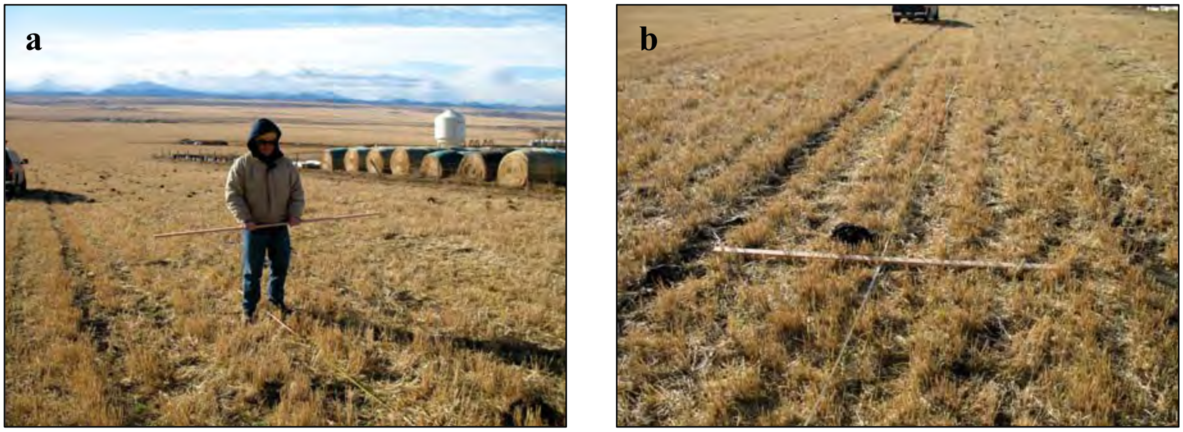

Figure 3.54. Fecal pat counting by (a) walking along a tape measure with 2-m stick and (b) a view of the transect at Hotspot 6 with measuring stick in November 2009.

3.6.2.5 Water Flow and Quality

The NMF site was monitored by a single edge-of-field water quality monitoring station. Station 4 was equipped with a circular flume and an Isco water sampler. The flume and Isco were located in the grass drainage channel within the field about 260 m upstream from the dugout (Figures 3.53 and 3.55). The grass channel continued about 540 m upstream of the monitoring station. The snowmelt samples collected from 2008 to 2011 were from snow in the drainage channel and some of the water was pooled in the channel at the flume due to blockage by snow and ice. The pooled water was subtracted off the total volumes and attempts were made to collect flowing water outside of the pooled areas. Flow data were not collected during the 2007 snowmelt event because the instrumentation was not yet operational. Snowmelt generally occurred in March and April and rainfall runoff occurred in May and June at this site. Daily loads were determined by multiplying the total daily volume by the water quality concentrations in the sample collected that day and total annual loads were the sum of all the daily loads. Flow on days when no samples were collected was added to the closest day that did have a sample in order to account for this flow. The pre-BMP monitoring period was from 2007 to spring 2010. The BMP plan was implemented for the fall grazing period in 2010. The only post-BMP water samples collected were in spring 2011. No samples were collected in 2012 because of lack of runoff. There were 24 pre-BMP and 10 post-BMP snowmelt samples, and 18 pre-BMP and 5 post-BMP rainfall runoff samples collected at this site.

Statistical analyses of the water samples from an edge-of-field site comparing the pre- and post-BMP periods is described in Sub-section 2.8.4. Chloride (which was added as an additional parameter in late July 2008) was not included in the BMP phase analyses because there was not enough pre-BMP data.

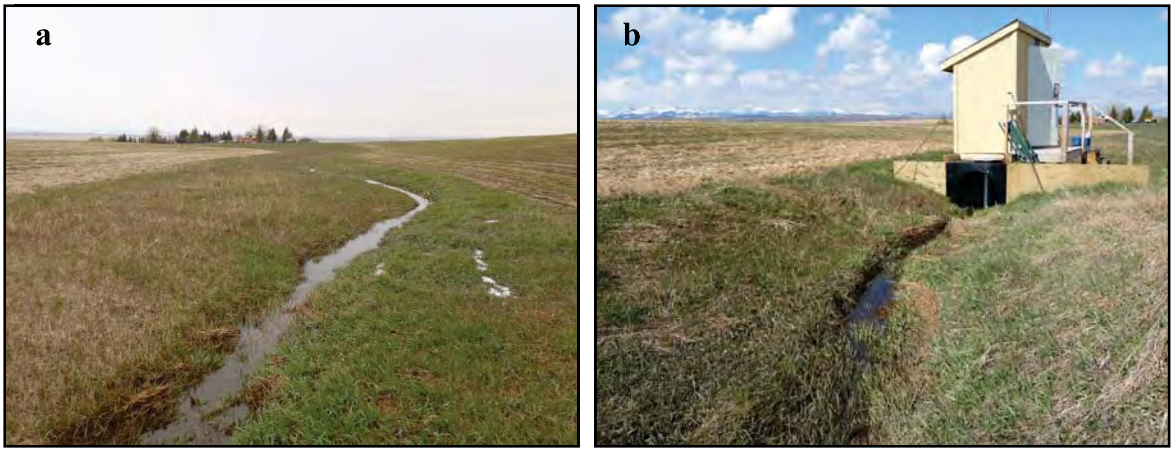

Figure 3.55. Images of the North Manure Field in May 2010 showing (a) the grass drainage channel with active water flow and (b) Station 4 installed in the channel. Both images are viewed downstream.

3.6.3 Results and Discussion

3.6.3.1 Implementation of Beneficial Management Practices

The use of an electric fence at the NMF site was successful in excluding the cattle from the grass channel in fall 2010. However, because of winter conditions, the cattle were in the field for only 18 d (Table 3.23). The temperature reached nearly -30 ^{o}C when the cattle were in the field and the cattle had to be fed in the field because of snow cover. Regardless, no new fecal pats were deposited in the drainage channel in fall 2010.

In fall 2011, it was decided not to re-install the electric fence. After further assessment and discussions, even though fencing is very effective at excluding cattle from an area, it was felt that in this situation (i.e., grass channel in an annual cropped field) excluding cattle would not be practical. Annual re-installation and maintenance of the electric fence was not desirable. Though more costly, a permanent fence would be better, and would not require annual re-installation. However, for this field, a permanent fence was not practical because the producer drives equipment through certain sections of the grass channel during normal field operations.

Without a physical barrier to prevent cattle access to the grass channel, other options were discussed on how to manage cattle distribution away from the channel. The use of portable windbreaks was considered. However, creation of 'hotspots' in the field caused by cattle congregating around windbreaks was not desirable. Plus, several windbreaks would have been required for 200 animals (i.e., the herd size in 2009 and 2010). Therefore, no BMP plan was implemented to encourage cattle away from the grass channel at the NMF site in fall 2011 and was only applied at this site in fall 2010. As it turned out, a much smaller herd (80 animals) occupied the field in 2011 compared to 2009 (224 animals) and 2010 (200 animals), and this may have resulted in less impact on the drainage channel.

As indicated previously, the off-stream watering system used at the FEN site did not function properly in fall 2010 due to cold weather conditions and problems with the power system. As a result, a portion of the newly constructed barbwire fence had to be removed to allow cattle access to IFC for water. Even though this BMP of preventing access to the creek did was not successful in 2010, the cattle were only in the field for 18 d. This site demonstrated that unforeseen circumstances (cold weather), mechanical failures (off-stream watering system), and the need to provide essentials (water for livestock) can compromise well intended BMPs. It also demonstrated that the adoption of certain BMPs may mean a change from a practice that required very little to no management (i.e., direct access to a natural source of water) to a practice that may rely on an engineered system, which requires more management and maintenance and in the event of a failure, a backup plan.

In 2011, the fence at the FEN site was reassembled and the cattle were successfully excluded from IFC at the south end of the field. Because this BMP could not be implemented in fall 2010, the pre-BMP period for this site was from 2007 to 2011, and 2012 was the only post-BMP year during the study at this site.

The retaining wall constructed at the FEN site to prevent erosion by runoff from the field was not successful. Rather than using an engineered barrier, bioengineering may have been more successful. This would have required some excavation to reduce the slope of the eroded area and establishment of permanent vegetation up gradient from the eroded area and into a portion of the field. Though relatively small, a portion of the field would have to be taken out of production. A larger area would then have to be fenced to prevent cattle access to the creek.

The total cost of the BMP implementation and maintenance was nearly $11,000 (Table 3.25). Nearly 70% percent of this cost was for the off-stream water system. The retaining wall was considered more of a reclamation activity rather than a BMP, and was about 8% of the total cost. Even though the BMPs were not successful in terms of implementation or practicality, the equipment purchased (i.e., electric fence and off-stream water systems) could be re-used elsewhere, or sold to recover some of the cost. The barbwire fence was a modest cost, as the distance fenced was relatively short. A contractor was used to construct the fence. Construction cost could have been less if the landowner had installed the fence.

3.6.3.2 Soil

Agronomic samples. Extractable NO_3-N, extractable ammonium N (NH_4-N), and STP concentrations in the 0- to 15-cm agronomic samples were generally higher in the spring compared to the fall (Table 3.26). This was more so for extractable N than for STP. The lower concentrations in the fall were likely due to crop uptake. The higher spring NO_3-N concentrations may have also been influenced by fertilizer application, since soil sampling was collected after this field operation. On average, about 125 kg ha^{-1} of fertilizer N was applied to this site in the spring (Table 3.23). However, in 2010, spring NO_3-N was quite low. In 2010, seeding and fertilizing was completed by April 8, but due to wet weather and soil conditions, soil samples were not collected until June 7. Taking into account above average precipitation in April and May (Sub-section 3.2) and the delayed soil sampling, the low NO_3-N concentration in spring 2010 may have been caused by leaching.

Table 3.25. Cost of beneficial management practices at the North Manure Field and Fencing sites.				
Site	Year	Item	Cost ($)	Labour (h)
North Manure Field	2010	Electric fence[z]	822	8
		Total	**822**	**8**
Fencing	2010	Fences A and B - materials	879	12
		Fences A and B - contractor	1,800	-
		Retaining wall[y]	600	12
		Kellin solar water system	7,450	2
	2011	Alfalfa seed	260	3
		Total	**10,989**	**29**

[z] Fiberglass electric fence posts costs were estimated.
[y] Landscape fabric and PVC pipe costs were estimated.

Soil-test P was neither low nor excessive at this site (Table 3.26). The 2007 to 2011 average was 46 mg kg^{-1} in the 0- to 15-cm layer, and this concentration was less than the agronomic threshold of 60 mg kg^{-1} (Howard 2006). Annual cropped fields near a confined feeding operation are often high in P from frequent manure application. However, manure was applied infrequently at this site (every 5 to 7 yr) and this prevented the accumulation of excess P in soil.

In spring 2011, extractable NO_3-N was significantly increased from pre-seeding to post-seeding (Table 3.27). The pre-seeding samples were collected 17 d prior to seeding and the post-seeding samples were collected 24 d after seeding. The amount of N fertilizer applied with the seed in 2011 was 119 kg ha^{-1} (Table 3.23), which was more than enough to account for the increase in NO_3-N within the 0- to 15-cm soil layer. The concentrations of NH_4-N and STP were also higher after seeding; however, the differences were not statistically different (Table 3.27). Only a small amount of P fertilizer (7 kg ha^{-1}) was applied in spring 2011.

Soil-test samples. Extractable NO_3-N, NH_4-N, and STP concentrations were similar in that the highest concentrations were found in the top 0- to 15-cm layer and then decreased with depth (Table 3.28). Stratification of STP was more prominent, with much higher concentration in the 0- to 15-cm layer compared to the two deeper layers.

The purpose of the soil-test samples was to provide nutrient management plans for manure application, and as there were no imminent plans for manure application, soil-test sampling was not carried out in 2011. Using the fall 2010 results (Table 3.28) and the Alberta Farm Fertilizer Information and Recommendation Manager (AFFIRM) program (ARD 2008), 25 to 45 kg ha^{-1} of N fertilizer and no P fertilizer was recommended for the 2011 crop year. However, in spring 2011, 119 kg ha^{-1} N and 7 kg ha^{-1} P were applied (Table 3.23).

Table 3.26. Average nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) values for agronomic soil samples collected from 2007 to 2012 and the drainage channel samples collected in 2008 and 2009 at the North Manure Field.

	NO_3-N		NH_4-N		STP	
	Spring	Fall	Spring	Fall	Spring	Fall
Year	(mg kg^{-1})					
	Agronomic samples					
2007	46	15	12	6	70	53
2008	60	15	8	5	39	78
2009	27	11	5	6	53	40
2010	5	8	7	6	69	38
2011	25	20	17	4	62	19
2012	39	-	17	-	40	-
	Drainage channel samples					
2008[z]	-	6	-	6	-	82
2009[y]	-	7	-	13	-	121

[z] Samples collected from the 0- to 15-cm soil layer using a Dutch auger.
[y] Samples collected from the 0- to 2.5-cm soil layer using the frame excavation method.

Table 3.27. Average nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) concentrations in pre- and post-seeding soil samples collected at the North Manure Field in 2011.

	NO_3-N	NH_4-N	STP
	(mg kg^{-1})		
Pre-seeding[z]	6*a*[y]	4*a*	30*a*
Post-seeding[x]	25*b*	17*a*	62*a*

[z] Pre-seeding samples collected on May 3, 2011. The barley crop was seeded on May 20, 2011.
[y] Averages for each parameter followed by the same letter are not significantly different (P <0.1).
[x] Post-seeding samples collected on June 14, 2011.

Drainage channel samples. Average NO_3-N concentration was similar between the drainage channel and the field (i.e., agronomic samples) in 2008 and 2009 (Table 3.26). Ammonium N concentration in the drainage channel was similar in 2008 and about double in 2009 compared to the field. Soil-test P concentration was higher in the drainage channel as compared to the field. Concentration of STP was higher in the 0- to 2.5-cm soil layer compared to 0- to15-cm soil layer. Soil P is not very mobile in soil, and P distribution will stratify with the higher concentration near the surface (Olson et al. 2010b). The undisturbed channel surface, decomposition of plant residues, and the addition of fecal pats from cattle (Sub-section 3.6.3.3) may have contributed to the higher STP concentration in the drainage channel. Therefore, the higher STP concentration in the channel soil surface may result in higher P in runoff water than what may be expected in runoff from the cropped field.

Table 3.28. Soil-test results for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for samples collected at the North Manure Field in fall 2010.

	NO_3-N	NH_4-N	STP
Soil layer (cm)		(mg kg^{-1})	
0 to 15	6	6	48
15 to 30	3	3	2
30 to 60	3	2	1

3.6.3.3 Cattle and Fecal Pat Distribution

Cattle distribution. The distribution of cattle in the field varied among the days and with time per day in November 2009. The cattle were often in groups; however, they were sometimes spread throughout the field (Figure 3.56). At times, nearly the whole herd was in one quadrant, such as on November 4 at 9:00 when 92% of the herd was in Quadrant A3 (Figure 3.57a). At other times, the herd was more evenly distributed among the six quadrants, such as on November 19 at 15:00 (data not shown). The cattle were observed at water sources on a regular basis.

In the morning on the first day of observation (November 4), a majority of the herd was in Quadrant A3, where the cattle had direct access to IFC (Figure 3.57a). In the afternoon, the herd was more dispersed among the quadrants. However, about 78% of the herd was in Quadrant A1 at 15:00. This shows the herd moved from the north area to the south area between the two water sources available in 2009 (IFC at the south end and water troughs at the north end of the field). The distribution pattern was different on November 5. No one quadrant was strongly favoured, although at least some cattle were present in Quadrant A1 for each count, ranging from 10 to 53% of the herd (Figure 3.57b).

Averaging the counts from November 4 and 5 (Figure 3.57a,b) with the other 4 d of observations (data not shown) revealed an overall diurnal pattern of cattle distribution, at least during daylight hours. The herd had a strong tendency to congregate in the most southern two quadrants (A3 and B3) during the midday (Figure 3.57c). On average, 76% of the herd was present in these two quadrants at 12:00. In the early morning, there was a greater distribution of the herd in the central and northern quadrants, particularly in Quadrant B2. In the late afternoon, the herd shifted from the southern quadrants (A3 and B3) to the northern quadrants (A1 and B2) and the west-central quadrant (A2).

Figure 3.56. Cattle grazing in the North Manure Field in November 2009.

Overall, a majority (62%) of the herd occupied Quadrant A3, which had significantly more cattle than the other five quadrants (Table 3.29). Quadrant B1 had the least number of animals (23%), and the distribution was similar among the other four quadrants. The attraction in Quadrant A3 was likely access to water in IFC and some shelter in the lower riparian area. However, shelter requirements may have been minimal during the time of cattle observations (November 4 to 19, 2009) because the weather was relatively mild, stable, and dry. The average daily temperature ranged from -2.3 to 9.6 ^{o}C during this period with only a trace amount of precipitation. The ground surface was free of snow. The monthly mean daily temperature for November 2009 was 2.48 ^{o}C, which was above the 30-yr average of -1.4 ^{o}C (Environment Canada 2009). Under more severe weather conditions, the cattle may spend more time in the sheltered area, although under colder conditions, water in the IFC may be frozen and the only source of water would be in Quadrant A1 (water troughs filled with piped water), except for snow when present.

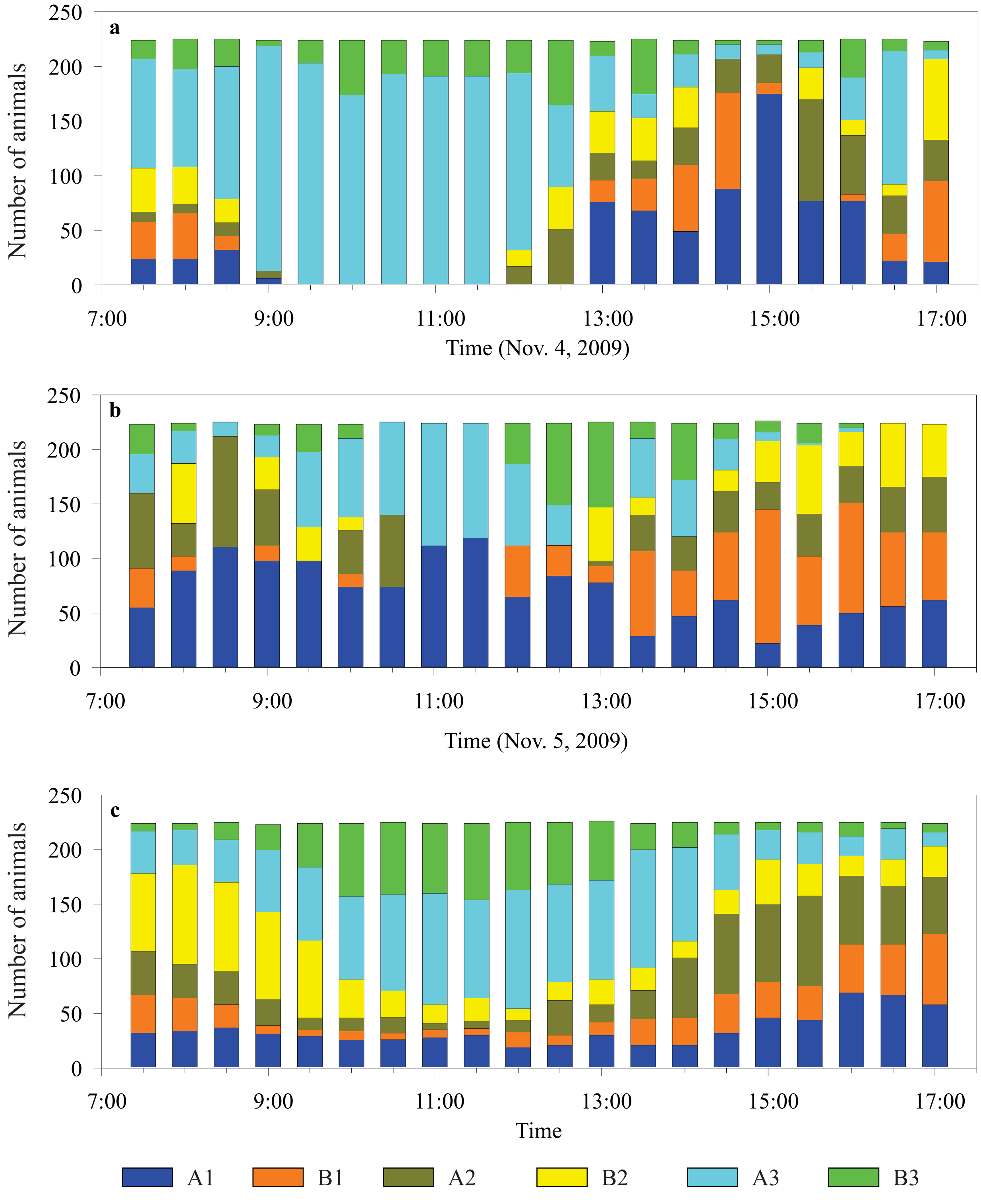

Figure 3.57. Cattle distribution counts for (a) November 4, (b) November 5, and (c) the 6 d of observation averaged (n = 60) for each time-of-day count in November 2009.

Table 3.29. Average counts of cattle at the North Manure Field in November 2009.

	Quadrant[z]					
Date	A1	B1	A2	B2	A3	B3
Nov. 4[y,x]	37b	20b	23b	20b	101a	24b
Nov. 5	71a	38bc	33bc	23bc	40b	19c
Nov. 9	43ab	7c	53a	45ab	53ab	24bc
Nov. 12	25cd	17d	48ab	33cd	64a	38bc
Nov. 16	24c	38b	35bc	37bc	65a	25bc
Nov. 19	11b	19b	22b	65a	48a	59a
Overall[w]	35b	23c	36b	37b	62a	32b

[z] Each quadrant was about one quarter section (65 ha) in size. The grass channel was in Quadrant A2. The access point to Indianfarm Creek was in Quadrant A3. Water troughs were in Quadrant A1.
[y] n = 20 for average values for each date.
[x] Within each row, averages followed by the same letter are not significantly different ($P < 0.1$).
[w] n = 120 for average values for the 6 d of observations.

Although some cattle were observed in Quadrant A2, they were not observed in the grass channel consistently during the first 3 d of observations. Cattle presence in the grass channel was more prominent during the latter days of observations. On November 12, it was noted that approximately 25 animals were present in the east end of the grass channel most of the afternoon. The same cattle were not present for the entire time, but there were always approximately 25 animals present. During the period of observation, the grass channel showed increased evidence of cattle presence. The grass was grazed close to the ground and there were many fecal pats present compared to the surrounding area (Figure 3.58).

Cattle distribution data expressed as number of animals per quadrant were limited in identifying potential problem areas. A finer grid pattern may have improved the sensitivity of the survey. For example, it was suspected the grass channel may have attracted the cattle. However, the quadrant that contained the grass channel (A2) did not have a particularly high proportion of the herd, was significantly less than Quadrant A3, and was not significantly different from Quadrants A1, B2, and B3 in 2009 (Figure 3.57c, Table 3.29). The cattle survey did, however, highlight a preference to Quadrant A3, where cattle had access to water and shelter. It was the more detailed visual observations during the survey that located specific areas of cattle congregation and these areas were later confirmed and quantified with the fecal pat survey. In terms of risk to runoff water quality, Hotspot 1, where cattle had direct access to IFC in 2009, and the grass channel in Quadrant A2 were areas of concern and where BMPs could be directed (Figure 3.53). Hotspot 1 was not within the drainage area of Station 4 (NMF site); however, it was only a short distance upstream from Station 12 at the WIN site.

Fecal pat distribution. Average fecal pat density values showed a similar trend among the main areas within the field in 2009 and 2011. The highest average density was in the grass channel and the lowest average density was in the quadrant centres, which were significantly different, with the hotspots in between (Table 3.30). The average fecal pat density was 29- to 73-fold greater in 2009 and 41- to 51-folder greater in 2011 in the grass channel compared to the quadrants. The higher density in the grass channel may indicate a preference for grass over crop residue for feed, shelter

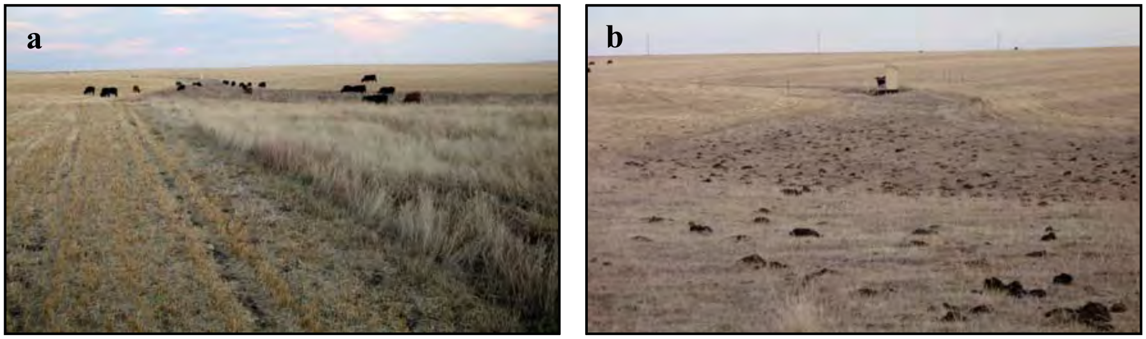

Figure 3.58. Views of the grass channel looking east towards Station 4 on (a) November 5 and (b) November 16, 2009.

in the lower grass area, and shelter from the nearby farmyard. The west side of Station 4 had a fecal pat density significantly greater than the east side of Station 4 in 2009 (Table 3.30). The density was also higher in the west grass channel in 2011; however, the averages between east and west were not significantly different. Although observations were not taken at night, we suspect many of the animals used the west channel as a bedding area, particularly in 2009.

In addition to the grass channel, six hotspots were identified where cattle congregated in 2009 (Figure 3.53). The hotspots had fecal pat densities that were similar to those found in the east grass channel (Table 3.30). The areas near a water source and shelter had the greatest number of fecal pats. Hotspot 3 had the highest fecal pat density (7150 pats ha^{-1}) among the six hotspots. There was shelter from the wind near the farmyard and this location was not far from the water source (water troughs) near Hotspot 2 (Figure 3.53). Hotspot 1 yielded the next highest fecal pat density and this was not surprising as this location was near the mainstem of IFC, where cattle had access to water in 2009. When the cattle drank from IFC at this location, they also had some shelter (Figure 3.59a). The counts at Hotspots 4 and 6 had the next highest fecal pat densities.

Table 3.30. Fecal pat density at the North Manure Field site in the fall 2009 and fall 2011.

Grass channel – east of Station 4			Grass channel – west of Station 4		
Transect[z] (m)	2009	2011	Transect[z] (m)	2009	2011
	-------- (pats ha^{-1}) --------			-------- (pats ha^{-1}) --------	
0-100	6850	1550	0-100	6,700	1,250
100-200	6200	1150	100-200	14,100	2,050
200-300	3750	2050	200-228	13,781	11,875
300-400	5350	5450	*Average*	*11,527a*	*5,058a*
400-500	4050	5900			
500-535	1000	8571			
Average[y]	*4533b*	*4112a*			
Quadrant centres			**Hotspots**		
Transect[x] (m)	2009	2011	Transect[x] (m)	2009	2011
	-------- (pats ha^{-1}) --------			-------- (pats ha^{-1}) --------	
A1	100	100	1	6350	100
A2	400	0	2	2100	850
A3	250	0	3	7150	3500
B1	50	0	4	4250	700
B2	150	350	5	500	50
B3	0	150	6	3600	0
Average	*158c*	*100b*	7[w]		1200
			8[w]		2000
			Average	*3992b*	*1050b*

[z] Transects were 2 m wide.
[y] Average values in the same year followed by the same letter are not significantly different ($P < 0.1$).
[x] Transects were 2 m by 100 m.
[w] Hotspots 7 and 8 were not surveyed in 2009.

Hotspot 4 was near a residence yard, but the cattle did not get much shelter from the wind at this location along the west fence near the yard. Hotspot 6 was close to Hotspot 3, and perhaps there was still some protection from the west wind at this location. Hotspot 2 was near a water source (Figure 3.59b), but cattle were exposed to the west wind at this location. Hotspot 5 was not near a water source and cattle were exposed to the wind along the north side of the yard. This location had the lowest fecal pat density of all the hotspots in 2009. In 2011, Hotstops 1, 5, and 6 had fecal pat densities equal to or less than the average density for the quadrants. Therefore, these areas were not a preference for cattle to linger in 2011. For Hotspot 1, cattle had nearby access to IFC as a water source in 2009; whereas, in 2011, the cattle were excluded from the access point to the creek with fencing. It is uncertain what may have caused the preference change for Hotspots 5 and 6 between 2009 and 2011. Even though the cattle could not access IFC at the south end of the field, it is interesting that Hotspot 7 developed nearby (Figure 3.53). It is unclear what would have attracted the cattle to this area of the field in 2011. Amongst the hotspots in 2011, Hotspots 3 and 8 had the highest densities and Hotspot 2 had the fourth highest density of fecal pats. All three of

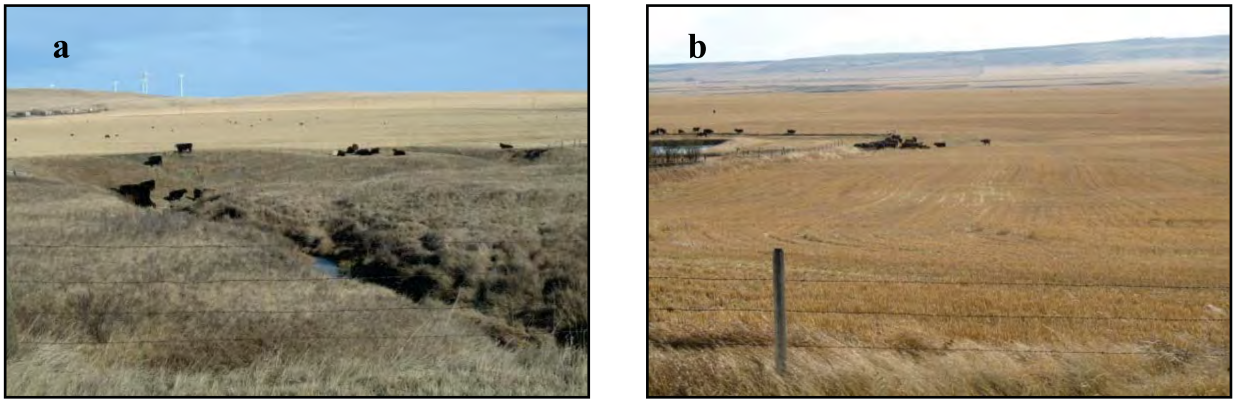

Figure 3.59. Views of (a) Hotspot 1 near the IFC main stem at the south end of the North Manure Field and (b) Hotspot 2 near a water source at the north end of the North Manure Field.

these sites were in proximity of the watering troughs and salt block at the north end of the field. The average density in the east grass channel was similar between the 2 yr. The density tended to be higher in the west section of this portion of the channel (i.e., near Station 4) in 2009; whereas, the density tended to be higher in the east section of the channel in 2011. Possibly, the addition of a mineral lick station near the east end of the grass channel may have caused the cattle to linger more in the eastern end of the channel.

3.6.3.4 Water Flow and Quality for the NMF

Water flow. Surface runoff occurred only in the spring season (March to June) at the NMF site during the study period (Figure 3.60). Approximately 22% of the 6-yr total flow (243,050 m^3 yr^{-1}) was due to snowmelt and 78% was due to rainfall at this site from 2008 to 2011 (Table 3.31). More than half (54%) of the 6-yr flow occurred in 2011, which was the first year of the post-BMP period. About 40% of the 6-yr flow occurred in 2010, which was the last year of the pre-BMP period. Therefore, comparable high flows occurred during both BMP periods. Annual flows and the distribution between snowmelt and rainfall varied considerable during the study period. For example, all of the runoff in 2009 was derived from snowmelt; whereas, rainfall caused nearly all of the runoff in 2010 (Figures 3.61 and 3.62). As well, the largest volume of runoff occurred in 2011 and no runoff occurred in 2012. Much of the snow that accumulated in the field (Figure 3.61a) disappeared through sublimation caused by warm Chinook winds during winter prior to the spring melt. The small amount of snowmelt runoff that did occur in 2008 and 2010 was mostly due to snow accumulation in the drainage channel (Figure 3.61b).

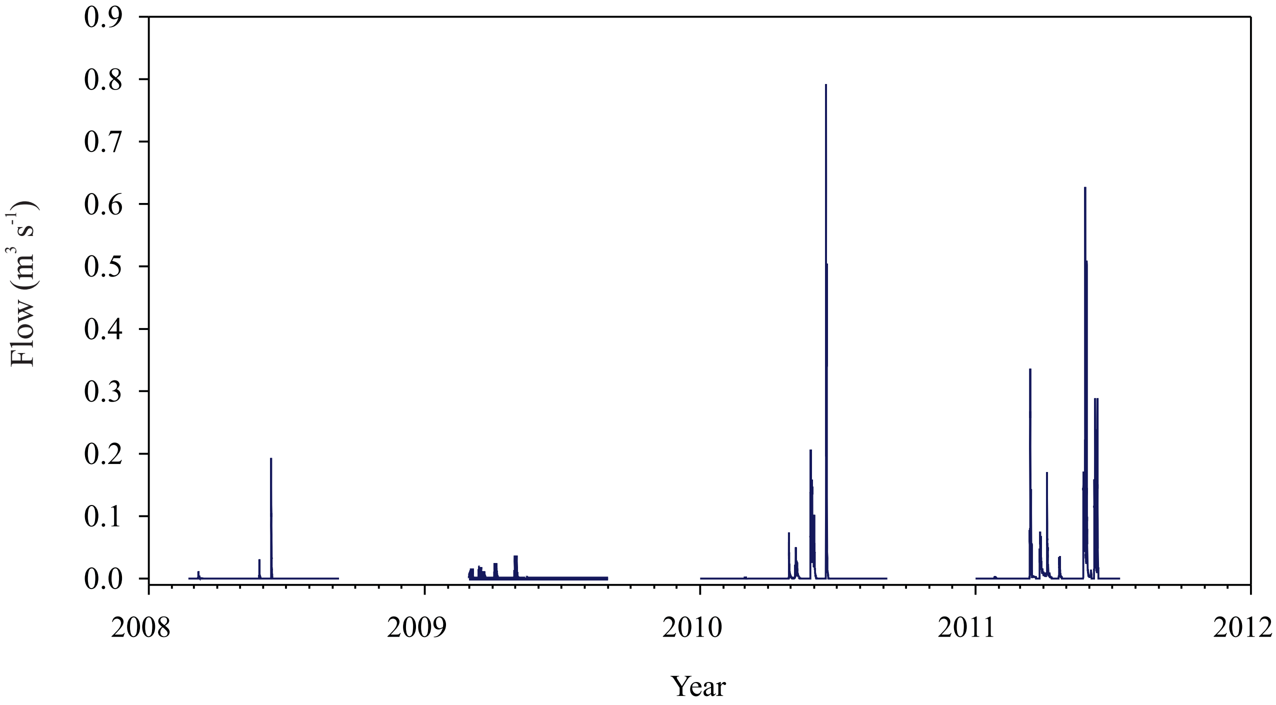

Figure 3.60. Hydrograph for the North Manure Field water monitoring station from 2008 to 2011.

Table 3.31. Annual flow and proportions of flow attributed to snowmelt and rainfall runoff at the North Manure Field site from 2008 to 2011.

Year	Flow (m^3 yr^{-1})	Proportion from snowmelt (%)	Proportion from rainfall (%)
2007	na[z]	100	0
2008	6,658	11	89
2009	7,681	100	0
2010	96,639	0.1	99.9
2011	132,072	34	66
2012	0	-	-

[z] na = not available. One runoff event occurred in 2007 and this was on March 6. The volume was not recorded because the field instrumentation was not yet installed.

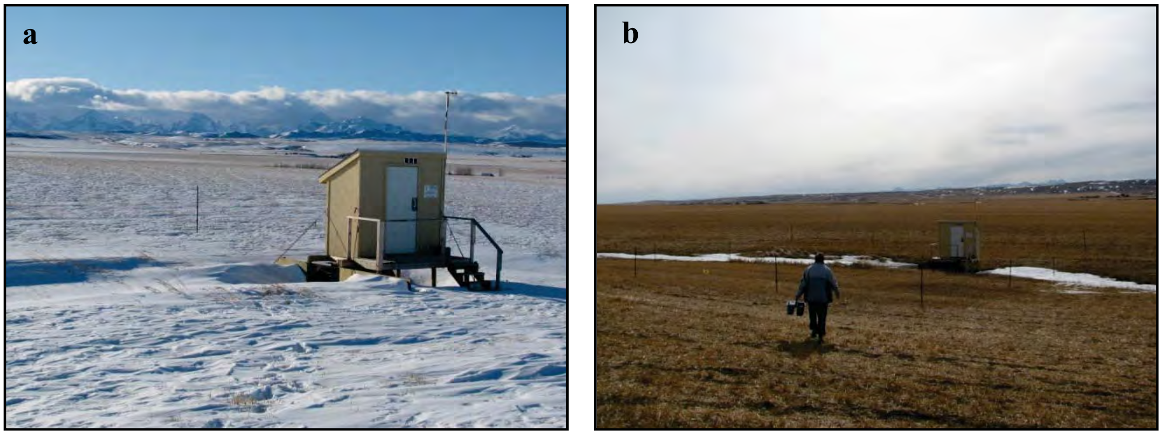

Figure 3.61. Snow-covered conditions at the North Manure Field near Station 4 on (a) December 17, 2009 and (b) on March 3, 2010.

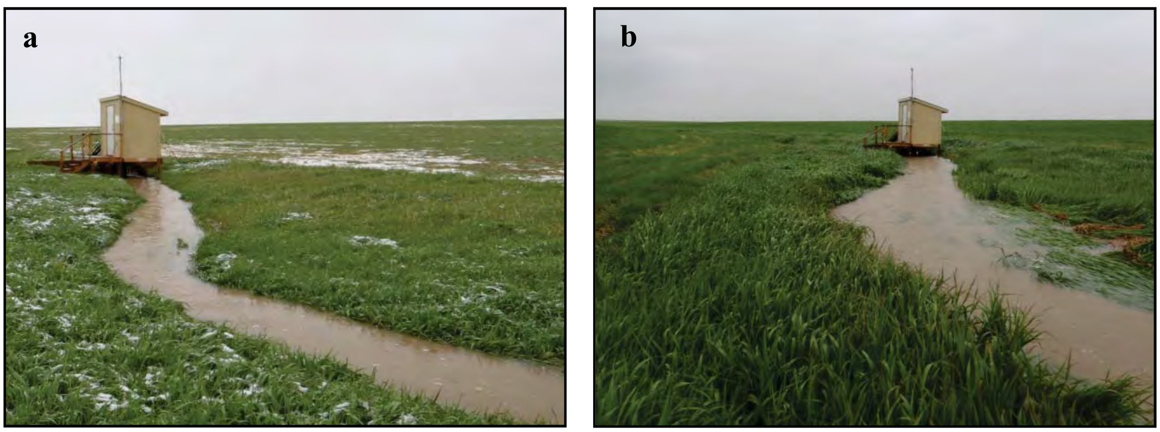

Figure 3.62. Rainfall runoff at Station 4 on (a) May 29, 2010 and (b) June 17, 2010.

General water quality observations. The maximum TN concentration increased each year from 2007 to 2011 at the NMF site (Figure 3.63a). This seemed to correspond to the increase in annual flow observed during this period (Table 3.31). In contrast, TP concentration in runoff was more consistent among years (Figure 3.63b). Total suspended solids concentration was also generally consistent among years, except in 2011 when higher peak concentrations occurred (Figure 3.63c).

On average, about 70% of TN in runoff was in soluble form (NO_3-N and NH_3-N), with NO_3-N as the dominant form (Table 3.32). Similarly, the majority of TP was in soluble form. On average among the years, the portion of TP in dissolved form was 90% during snowmelt and 84% during rainfall runoff. Therefore, at this site, the two major nutrients were mainly in dissolved form in runoff. The relatively low concentration of particulate nutrient forms was likely the result of the well vegetated drainage channel and zero tillage practiced on the field, of which both can minimize soil erosion by water.

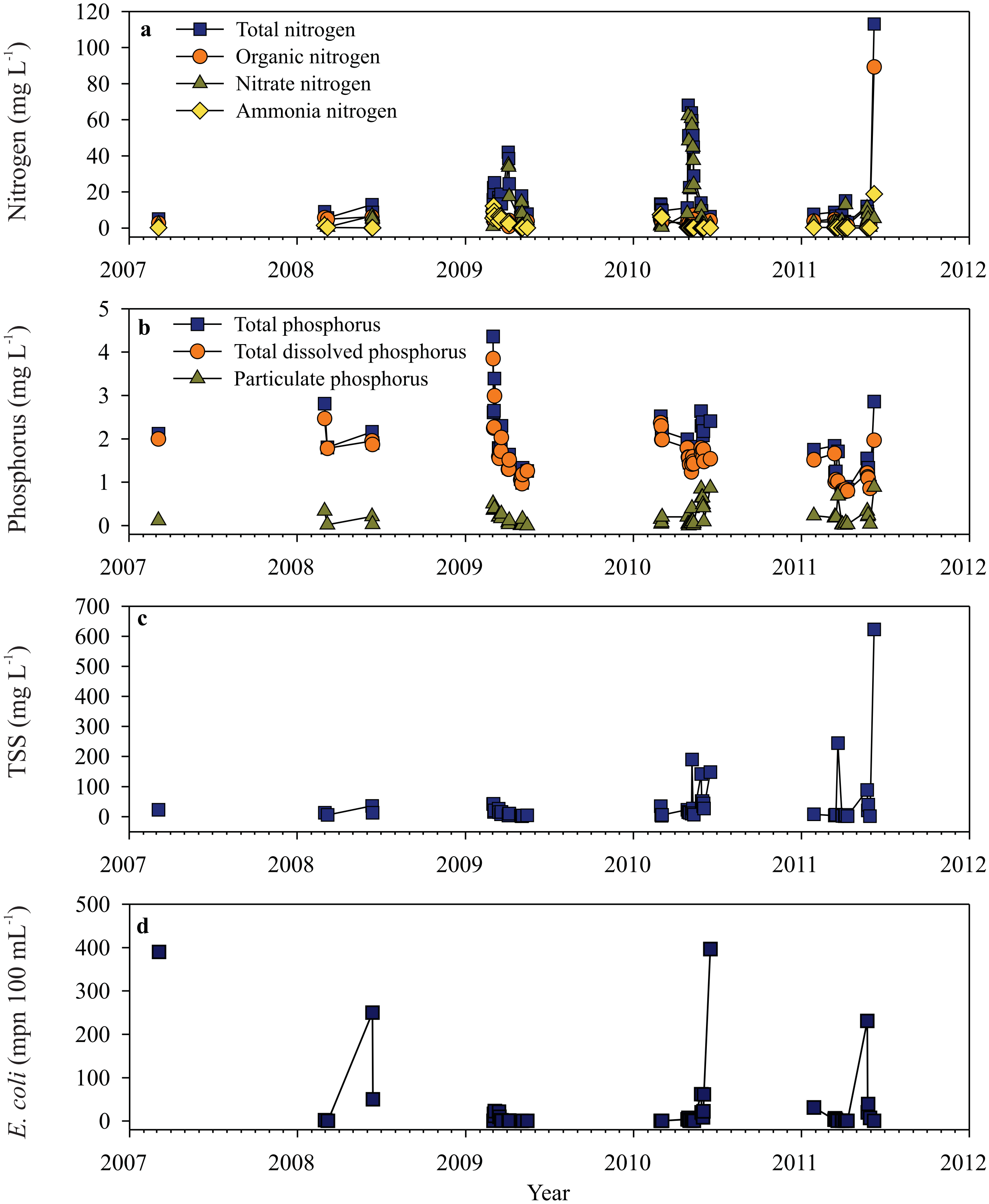

Figure 3.63. Concentration values in runoff water samples (snowmelt and rainfall) for (a) total nitrogen, organic nitrogen, nitrate nitrogen, and ammonia nitrogen; (b) total phosphorus, total dissolved phosphorus, and particulate phosphorus; (c) total suspended solids; and (d) *Escherichia coli* (*E. coli*) at the North Manure Field from 2007 to 2011.

Table 3.32. Average concentration of water quality parameters measured at Station 4 at the North Manure Field site from 2007 to 2011.[z]

Event	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli*	EC	pH
		($mg\ L^{-1}$)									(mpn 100 mL^{-1})	($\mu S\ cm^{-1}$)	
						Snowmelt							
2007	1	5.07	2.77	2.14	0.13	2.12	2.00	0.12	23	n/a[y]	390	185	7.60
2008	2	7.30	5.33	1.11	0.82	2.31	2.13	0.18	10	n/a[y]	1	271	7.35
2009	17	18.3	4.30	9.78	3.77	1.88	1.71	0.17	14	18.0	5	491	7.92
2010	4	11.4	3.92	1.22	6.23	2.27	2.16	0.12	13	16.0	1	428	7.73
2011	10	6.45	2.90	3.33	0.14	1.19	1.03	0.17	28	23.8	5	526	7.59
All	34	13.0	3.86	6.14	2.71	1.76	1.59	0.16	18	19.6	16	472	7.76
						Rainfall							
2008	2	10.8	4.88	5.87	0.03	2.03	1.91	0.12	25	n/a[y]	150	543	8.00
2010	16	28.2	3.63	24.4	0.09	1.87	1.57	0.31	51	17.3	38	738	8.04
2011	5	28.8	19.2	5.88	3.79	1.59	1.25	0.34	155	10.3	60	602	7.94
All	23	26.8	7.11	18.8	0.89	1.83	1.53	0.30	71	15.7	53	691	8.01

[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, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] This water quality parameter was added in late July 2008 (number of samples shown in parentheses).

The concentration of most N forms were two- to three-fold higher on average in rainfall runoff compared to snowmelt runoff, except for NH_3-N, which had a lower concentration in rainfall compared to snowmelt runoff (Table 3.32). Average TP and TDP concentrations were similar between the two runoff types; whereas, PP concentration was nearly two-fold higher in rainfall than in snowmelt runoff. The concentration of TSS was nearly four-fold higher in rainfall runoff compared to snowmelt runoff, and this likely contributed to the higher PP concentration in rainfall runoff. Average EC concentration was about 50% higher in rainfall compared to snowmelt. In contrast, average Cl concentration was about 20% less in rainfall compared to snowmelt runoff. The lower concentrations of some nutrient forms and TSS during snowmelt runoff may have been due to frozen soil.

Escherichia coli concentration was generally lower in snowmelt runoff compared to rainfall runoff (Table 3.32). The higher *Escherichia coli* concentration during rainfall runoff is likely due to greater microbial activity caused by higher air temperatures. The one exception was the relatively high *E. coli* concentration found in the single snowmelt sample collected in March 2007 (Figure 3.63d, Table 3.32). Typically, runoff bacteria concentrations are lower during snowmelt because of cold temperature. Perhaps wildlife or cattle fecal pats in the drainage channel may have been the source, particularly since air temperature in March 2007 was above normal (Sub-section 3.2).

The NMF site received manure relatively infrequently, about once every 5 to 7 yr. The soil data showed that excessive nutrients have not accumulated in this field. However, STP concentration was slightly higher in the drainage channel compared to the surrounding field (Sub-section 3.6.3.2). Cattle observations and fecal pat counts in fall 2009 showed that the cattle spent time in the drainage channel while fall grazing. The cattle deposited a high density of fecal pats upstream and downstream from the water monitoring station compared to the rest of the field (Table 3.30). It is likely that the extensive accumulation of fecal pats in the channel contributed nutrients to the runoff at this site (Figure 3.64).

BMP effects on water quality. Overall at the NMF site, runoff concentrations of TN, NO_3-N, NH_3-N, TP, TDP, and pH were significantly less during the post-BMP period (2011 and 2012) compared to the pre-BMP period (2007 to 2010) (Table 3.33). Total N and TP concentrations were about 32% less in the post-BMP period. Other reductions in concentration included 32% for NO_3-N, 70% for NH_3-N, 38% for TDP, and 3% for pH. These reductions were mainly due to reductions in concentration in snowmelt runoff during the post-BMP period. The concentration of *E. coli* was 30% less in the post-BMP period; however, this was not significantly different from the pre-BMP period.

The concentrations of PP and EC were similar between the two periods, and ON concentration was significantly higher in the post-BMP period (Table 3.33). The concentration of TSS was 2.5-fold greater in the post-BMP period; however, it was not significantly different from the pre-BMP period.

The BMP at the NMF was implemented in fall 2010, and 2011 was the first post-BMP monitoring year. The cattle were excluded from the drainage channel and no new fecal pats accumulated in the channel in 2010. The BMP was not repeated in fall 2011 and the cattle had access to the drainage channel. However, there was no spring runoff in 2012. Therefore, the pre-BMP period was 4 yr (2007 to spring 2010) and the post-BMP period was only 1 yr (spring 2011). The total runoff volume in 2011 was 1.4- to 20-fold larger than in the previous 3 yr of the study (Table 3.31). The larger volumes in 2010 and 2011 were due to above average precipitation (Sub-section 3.2). The much larger runoff volume in 2011 may have resulted in the higher TSS concentration in 2011 compared to pre-BMP period. The high TSS concentration may explain the significantly higher ON concentration; however, there was no change in PP concentration in the post-BMP period compared to the pre-BMP period.

Excluding cattle from the drainage channel in fall 2010 was effective in improving the quality of runoff water from the field. However, this was based on only 1 yr of post-BMP monitoring. Cattle grazing in the fall 2011 deposited fresh fecal pats in the drainage channel. The fecal pat density in the channel in 2011 was about 35% less than in 2009 (Table 3.30), likely due to the smaller herd in 2011 compared to 2009. Unfortunately, runoff did not occur in spring 2012. If runoff had occurred in 2012, we predicted an increase in concentration of many parameters in runoff compared to the 2011 results would have occurred. A high density of cattle fecal pats in a drainage channel intuitively would likely impact negatively the quality of runoff water (Figures 3.58 and 3.64).

As indicated in Sub-section 3.6.3.1, the BMP of excluding cattle from the drainage channel was discontinued after 1 yr. The grass drainage channel was a preferred attraction for the cattle and this resulted in a dense accumulation of fecal pats in the channel. Fencing to exclude the cattle from the grass drainage channel in a cropped field is likely impractical in terms of labour to annually re-install an electric fence or the cost of a permanent fence. Using fields for fall grazing that have minimal surface drainage and no vegetative channels may be a better alternative.

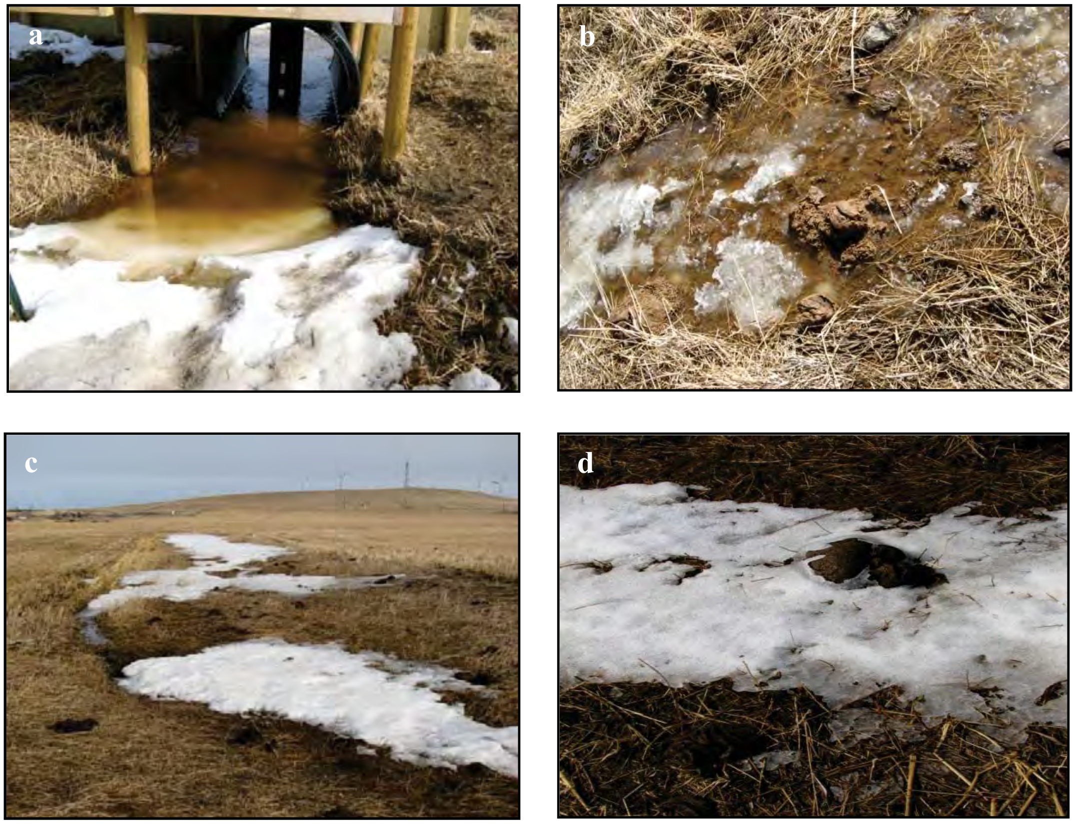

Figure 3.64. Snowmelt runoff water and manure in the drainage channel upstream of the monitoring station on (a,b) March 14, 2009 and (c,d) March 3, 2010.

Table 3.33. Average concentration of water quality parameters measured at Station 4 at the North Manure Field site in the pre- and post-BMP periods.

	Snowmelt		Rainfall		All events	
Parameter[z]	Pre-BMP (n=24)	Post-BMP (n=10)	Pre-BMP (n=18)	Post-BMP (n=5)	Pre-BMP (n=42)	Post-BMP (n=15)
TN (mg L^{-1})	15.7*a*	6.45*b*	26.3	28.8	20.2*a*	13.9*b*
ON (mg L^{-1})	4.26*a*	2.90*b*	3.77	19.2	4.05*b*	8.32*a*
NO_3-N (mg L^{-1})	7.32	3.33	22.4	5.88	13.8*a*	4.18*b*
NH_3-N (mg L^{-1})	3.78*a*	0.14*b*	0.08	3.79	2.20*a*	1.36*b*
TP (mg L^{-1})	1.99*a*	1.19*b*	1.89	1.59	1.95*a*	1.33*b*
TDP (mg L^{-1})	1.83*a*	1.03*b*	1.60*a*	1.25*b*	1.73*a*	1.10*b*
PP (mg L^{-1})	0.16	0.17	0.29	0.34	0.21	0.22
TSS (mg L^{-1})	13	28	48	155	28	71
Cl (mg L^{-1})	17.7*b*	23.8*a*	17.3	10.3	17.5	19.3
E. coli (mpn 100 mL^{-1})	20	5	51	60	33	23
EC (µS cm^{-1})	450	526	716	602	564	551
pH	7.83*a*	7.59*b*	8.03	7.94	7.92*a*	7.71*b*

[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, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity.

[y] Average BMP period concentrations per event followed by letters are significantly different at $P < 0.1$.

Annual loads of TN, ON, NH_3-N, TDP, and TSS were the largest in 2011 and NO_3-N, TP, and PP loads were the largest in 2010 (Table 3.34). The larger loads in 2010 and 2011 can be attributed to the larger runoff volumes in these years compared to the previous 3 yr. For some parameters, such as TN, even though concentration was significantly reduced in the post-BMP period, the loads were much larger in the post-BMP period compared to the pre-BMP period. However, the BMP implemented at this site was not designed to control runoff volume. We speculate that if the BMP was not implemented or not effective, the loads in runoff would have been even larger in 2011.

3.6.4 Conclusions

- The implementation of the BMP to exclude cattle from IFC at the FEN site was only successful in one out of two years. The year BMP implementation was unsuccessful demonstrated that unforeseen circumstances, such as early winter conditions in this case, can compromise a change in practice.

- Even though associated with a nearby feedlot, infrequent application of manure (i.e., once every 5 to 7 yr) to the NMF site prevented the accumulation of excess P in the soil. This was the practice already used for this site, and it demonstrated an effective, existing BMP for manure management to prevent the accumulation of soil nutrients and reduce the risk of nutrient loss to runoff.

- A grass drainage channel in a cropped field, which was used for fall grazing, was attractive for cattle. Cattle lingered extensively in the channel and caused an accumulation of fecal pats in the channel, and these fecal pats were exposed to runoff water.

Table 3.34. Annual loads of nutrients and total suspended solids in runoff at the North Manure Field site from 2007 to 2011.

	TN[z]	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
Year	(kg yr^{-1})							
2007	n/a[y]	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2008	79.8	39.7	39.6	0.32	14.1	12.8	1.22	213
2009	155	29.7	85.7	35.5	14.7	13.3	1.40	128
2010	1114	352	753	7.14	227	156	70.4	10,928
2011	4679	3365	651	666	219	172	47.3	24,198
2012[x]	0	0	0	0	0	0	0	0

[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.
[y] No flow data were collected in 2007 because the flow instrumentation was not operational.
[x] No runoff occurred at Station 4 in 2012.

- On average, the majority (78%) of the runoff volume from NMF was caused by rainfall events. However, this varied among years with total runoff caused by only rainfall or snowmelt in some years.

- The concentrations of most N parameters, TSS, *E. coli*, EC, and pH were larger in rainfall runoff than in snowmelt runoff. Phosphorus parameters and Cl concentrations were similar between snowmelt and rainfall runoff.

- The BMP of excluding cattle from the drainage channel (site NMF) had a positive effect on the quality of runoff water. Overall, concentrations of TN, NO_3-N, NH_3-N, TP, TDP, and pH in runoff were significantly less during the post-BMP period (2011 and 2012) compared to the pre-BMP period (2007 to 2010). However, this was based on 4 yr of pre-BMP data and 1 yr of post-BMP data. Additional monitoring would be required to confirm this effect.

- The results, based on 1 yr of post-BMP data, verified the hypothesis that the implemented BMP at the NMF site of excluding cattle from the grass drainage channel would improve water quality. The dissolved forms of nutrients were affected more by the BMP than the particulate forms.

- Preventing the accumulation of fecal pats in the drainage channel reduced the risk of water quality degradation. However, fencing to exclude the cattle from a drainage channel in a cropped field is likely impractical in terms of labour to annually re-install an electric fence or the cost of a permanent fence. Using fields for fall grazing that have minimal surface drainage and no vegetative channels may be a better alternative.

3.7 Pasture Site

3.7.1 Introduction and Hypotheses

The PST site included tame and native pastures used to graze cattle and where cattle had direct access to the mainstem of IFC. When in the pasture, cattle had unrestricted access to the creek as a source of water. In addition to the natural erosion processes in the creek, cattle access had degraded the riparian zone and enhanced stream bank erosion.

The BMPs implemented at the site included rotational grazing to control when cattle had access to the riparian area and removal of some corrals to reduce cattle congregation near the creek. The rotational grazing BMP was facilitated with electric and existing fences, an off-stream water system, and windbreaks. Although not part of the BMP plan, bioengineering was done at this site to reclaim some of the severely eroded creek banks. Upstream and downstream monitoring stations were used on the mainstem of IFC to monitor the south part of the PST site. As well, edge-of-field monitoring stations were used to monitor a small drainage channel, which was impacted by the old corral area. The post-BMP period began when the rotational grazing plan was initiated in mid-May 2010.

The underlying assumption is that cattle with direct access to IFC contributed nutrients and bacteria to the water. Also, riparian degradation caused by cattle, enhanced sediment and nutrient loss through rainfall and snowmelt runoff. Fecal pats in the riparian area also contributed to nutrients and bacteria during runoff events. The hypotheses were:

- The use of rotational grazing to reduce pressure on the riparian area would improve riparian quality along IFC, and in turn, reduce the concentration of nutrients (N and P), sediment, and bacteria in the creek. Rangeland quality in the pasture was also expected to improve.
    - Particulate nutrients were expected to be reduced more than dissolved nutrients because of improved bank stability and riparian quality. Bacteria would be reduced by minimizing the deposition of fecal pats in the riparian area along the creek.
- The removal of the corrals would reduce cattle attraction to an area near a drainage channel and this would result in reduced nutrient and bacteria concentration in water flowing through the channel and into IFC.
    - Dissolved nutrients were expected to be reduced more than particulate nutrients because the contributing area from the corrals and the drainage channel had existing grass and erosion potential was low. Bacteria would be reduced by preventing a high density of fecal pats in the contributing area.

3.7.2 Methods

3.7.2.1 Site Description and Management

The PST site was in the north, lower region of the watershed. It consisted of two adjacent quarter sections of land divided into a number of native and tame pastures. A farmyard was in the north quarter section as well as a small (11 ha) annual crop field (Figure 3.65) in the northeast corner. In Pasture A south of the farmyard and on the east side of the creek, were dilapidated, wooden corrals.

The area adjacent to IFC at the PST site was within the ZUN1/SC1l soil landscape model, as described by AGRASID (Alberta Soil Information Centre 2013). The soil in this model is an Orthic Regosol and includes miscellaneous undifferentiated material, with well drained characteristics. The landform in the model is described as a valley with a floodplain, and slopes ranging from 1 to 5% on the floodplain and up to 15% on the side slopes. Parent material is described as undifferentiated material. The surface soil had a clay loam texture (26.8% sand, 39.8 % clay), pH of 6.5, electrical conductivity of 1.4 dS m^{-1}, 5000 mg kg^{-1} TN, 896 mg kg^{-1} TP, and 12% organic matter (Appendix 4).

The area in the west half of the south quarter section and a portion of the north quarter section are within the CWY6/U1l soil landscape model (Alberta Soil Information Centre 2013). The soils in this model are Orthic and Rego Black Chernozems and include dominant (60% or more) Cowley soil series with a significant (10 to 30%) Oldman soil series. Landform in the model is described as undulating, with low relief and a limiting slope of 2%, and parent material consists of fine and medium textured water-laid sediments.

Indianfarm Creek flowed from south to north through the PST site. Pasture A was over grazed and stream bank erosion was evident in several places along the monitored reach. Stream-bank erosion was due to natural stream flow (Figure 3.66a), particularly during high-flow events, and direct cattle access to the creek (Figure 3.66b). The focus of the BMP plan and monitoring was on Pasture A (Figure 3.65) in terms of water quality (i.e., upstream/downstream), riparian health, and rangeland health. In April 2010, the annual crop field was seeded with a mixed forage blend (brome, fescue, alfalfa, and clover) and under-seeded with oats. The field was harvested as green feed at the end of September 2010 and then used to produce forage in 2011 and 2012. The field yielded 39 Mg ha^{-1} in 2011 and 45.5 Mg ha^{-1} in 2012. Pastures B and C were harvested periodically for forage, in addition to being grazed. The forage was harvested as round bales in 2011 and 2012 with a combined yield of 140.5 Mg ha^{-1} in 2011. Yield was not recorded in 2012. The bales were used for bale grazing in the winter.

From the early 1970s to about 1982, as many as 200 head of cattle pastured at this site and calving took place in the corrals south of the farmyard (Figure 3.65). In 1982, the herd size was reduced and by 1985 the corrals were no longer used for calving. However, the cattle continued to use the corrals for shelter when they were in the pasture and a thick manure pack developed (Figure 3.67a). There was also a high density of fecal pats in the immediate vicinity of the corrals (Figure 3.67b).

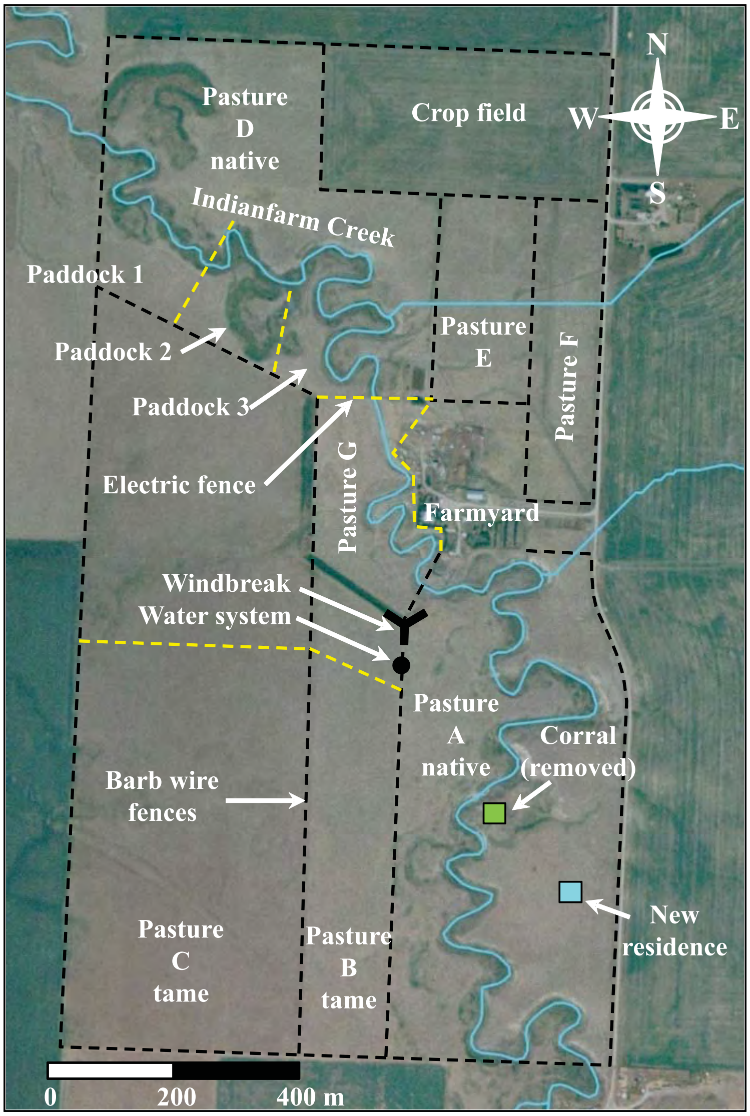

Figure 3.65. Pasture site management area showing the Pastures A to G and site infrastructure.

During the pre-BMP period (2007 to 2009), about 40 to 65 head of cattle grazed the PST site from October to June, except during the calving period from February to early spring when they were moved to the farmyard (Table 3.35). After calving, the cattle grazed the PST site until they were moved off site to a summer pasture until early fall. When the cattle were at the PST site, they grazed all pastures as needed but not always simultaneously. Cattle often had access to Pastures A and D while grazing other pastures because of the available water source from the creek. Pastures E and F had water available from the farmyard. The producer also had approximately 30 ewes and five to six rams that were present year round and penned separate from the cattle. There were also four horses on the property, and they were penned to the east and north of the farmyard.

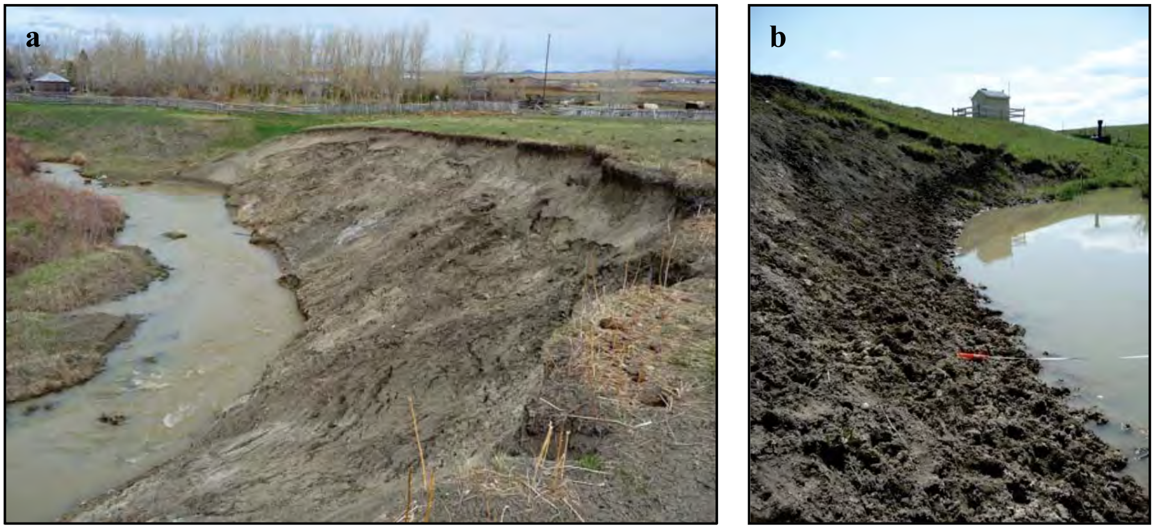

Figure 3.66. Pasture A showing (a) stream-bank erosion in May 2009 and (b) cattle-trail ruts and pugmarks adjacent to Indianfarm Creek in June 2009.

Figure 3.67. The corrals in Pasture A showing the (a) manure pack in April 2007 and (b) the nearby accumulation of fecal pats in March 2009.

3.7.2.2 Implementation of Beneficial Management Practices

After 3 yr of pre-BMP data collection during which existing management practices were carried out by the producer (Table 3.35), the BMPs were implemented in 2010. The main feature of the BMP plan was rotational grazing of cattle through the six to seven pastures available at the PST site (Pasture G was used only in 2011). To support the rotational grazing, an off-stream water supply was installed as well as windbreaks. Also included in the BMP plan was removal of the old corrals south of the farmyard in Pasture A.

The off-stream watering system and a permanent windbreak were installed between Pastures A and B, near the north end of the pastures (Figure 3.65). The watering system was a water trough (Edwards Livestock Water, Saskatoon, Saskatchewan; energy efficient, 125-head maximum capacity) on a 3- by 3-m concrete pad. Water was supplied under pressure through a 3.2-cm PVC underground pipe. The pipe was trenched 2.5 m deep, 400 m from an existing well at the farmyard. Electrical power for the trough was supplied from a new residence built within Pasture A. The

Table 3.35. Cattle management at the Pasture site during the pre-BMP period from 2007 to 2009.

Dates on site	Livestock[z]	Area grazed	Days on site
		2007	
Jan	40c	All pastures[y,x]	31
Feb	40cc	Farmyard barns and corrals	28
Mar to mid-Jun	40cc	All pastures	107
Mid-Jun to Sep 30[x]	40cc	Summer pasture[w]	0
Oct to Dec	40c[x]	All pastures[x]	92
		2008	
Jan and Feb	65c[x]	All pastures	59
Mar[x]	65cc[x]	Farmyard barns and corrals	31
April to Jun 2	65cc[x]	Pastures E and F[x]	63
June 3 to June 15	65cc	All pastures	13
June 16 to Oct 9	65cc	Summer pasture	0
Oct 10 to Oct 31	65cc	All pastures	22
Nov to Dec	65c	Alternate pasture off-site	0
		2009	
Jan to Feb 21	65c[x]	Alternate pasture off-site[x]	0
Feb 20 to Mar 30	65c[x]	All pastures	38
April[x]	65cc[x]	Farmyard barns and corrals	30
May[x]	65cc[x]	Pasture E and F[x]	31
Jun 1 to Jun 22	55cc	All pastures	22
Jun 23 to Oct 12	55cc	Summer pasture	0
Oct 13 to Dec 31	55c[x]	Alternate pasture off-site	0

[z] c = cows, cc = cow-calf pairs.
[y] All pastures utilized as needed but not simultaneously.
[x] Estimated because data not available.
[w] Cattle moved off site.

watering system provided water to cattle when they were in Pastures B and C and was a source of off-stream water when they were in Pasture A. When the cattle were only in Pasture C, an electric fence was used to direct the cattle to the watering trough and excluded them from most of Pasture B. The permanent wooden windbreak was constructed from September 8 to 11, 2009 and was 2.5 m high and 50 m long (Figure 3.68a). In addition to the permanent windbreak, a portable windbreak (2.6 m high by 9.3 m long) was used in Pastures E and F.

Removal of the old corrals in Pasture A (Figure 3.67a) was done on August 6, 2009 (Figure 3.68b). Removal of the manure pack and re-vegetating the site was also considered. However, the site was stable with existing vegetation and it was felt that removing the manure pack would expose the site to soil erosion until the vegetation re-established. Therefore, the manure pack and existing vegetation were left intact.

A rotational grazing plan was established to limit access of the cattle to the creek and riparian areas by utilizing all pastures more equally. This allowed for periods of rest when vegetative regrowth could occur. This was particularly important for Pasture A, through which IFC flowed (Figure 3.65). Pastures D and G also had riparian areas, but these two pastures were not monitored for BMP effectiveness. The rotational grazing plan also reduced grazing pressure on Pasture A to promote rangeland health recovery.

The number of breeding cows during the post-BMP period ranged from 42 to 48 animals (Table 3.36). The herd size was larger compared to 2007 and less compared to 2008 and 2009 (Table 3.35). During the post-BMP period, cattle were rotated through all pastures more equally than during the pre-BMP period and off-stream water was provided in most pastures. The producer continued to utilize the farmyard and corrals, along with Pastures E and F, during calving and spring months. Pastures A, B, D, and G were utilized until cattle left the PST site in June for summer pasture. When the cattle returned in October, they were rotated through Pastures A, B, C, E, and F. The new off-stream watering system allowed for independent grazing of Pastures B and C where water was not previously available. The watering system also provided a source of off-stream water for cattle when in Pastures A and G.

Three paddocks were established on the south side of the creek in Pasture D (Figure 3.65). Electric fencing was used to create the paddocks, each with a separate access to the creek for water. The cattle were only allowed to graze for a few days in each paddock. For example, in 2010, the cattle grazed 3 d in each paddock before they were moved to the north side of the creek in Pasture D for 7 d. Pasture G was created with an electric fence and was used for 4 d in June 2011.

3.7.2.3 Riparian Quality

The Alberta Riparian Habitat Management Society (known as Cows and Fish) carried out visual riparian health assessments (Sub-section 2.11.1) in 2007 and 2012 in Pasture A. The surveys were carried out on June 12, 2007 and June 12, 2012. Both sides of IFC were surveyed from INF2U to INF2L (Figure 3.69). The distance surveyed along the creek was 0.92 km and the riparian area width, including both banks of the channel, ranged from 10 to 45 m with an average of 30 m. The total riparian area (i.e., polygon) surveyed was about 2.8 ha in size.

Figure 3.68. Installation of the (a) permanent windbreak in September 2009 and the (b) corral site after the removal of the corral structure in early August 2009.

In addition to the Cows and Fish assessments, annual transect surveys were carried out from 2008 to 2012 (Sub-section 2.11.2). In 2008 and 2012, 20 transects were surveyed on either side and along the full length of IFC within Pasture A (Figure 3.69). Each transect consisted of two sub-transects, one on either side of the creek (e.g., 1A and 1B), for a total of 40 sub-transects. The sub-transects varied in length from 5 to 15 m. From 2009 to 2011, a random set of five transects was assessed each year (Table 3.37); however, these data are not presented in this report. Statistical analyses of changes in riparian community composition, species richness (SR), effective Shannon diversity (ED), and evenness (E), were carried out as described in Sub-section 2.11.2.

3.7.2.4 Rangeland and Production Cages

Rangeland quality was assessed in Pasture A using 10, 30-m long transects (Figure 3.70). The rangeland quality assessment was carried out in July each year and the survey methods are described in detail in Sub-section 2.12.1.

Table 3.36. Rotation grazing schedule of cattle at the Pasture site during the post-BMP period from 2010 to 2012.

Dates on site	Livestock[z]	Area grazed	Days on site
		2010	
Jan	46 c[y]	Alternate pasture off-site[y]	31
Feb	46c[y]	Pasture E & F	28
Mar	46cc[y]	farmyard and corrals[y]	31
April 1- May2	46cc[y]	Pasture E and F	32
May 3-14	46cc[y]	Road ditch	12
May 15 to 18	46 cc	Pasture B	4
May 19 to 27	46 cc	Pasture D[x]	9
May 28 to Jun 3	46 cc	Pasture D[w]	7
Jun 4 to 22	46 cc	Pasture A	19
June 23 to Oct 3	46 cc	Summer pasture	0
Oct 4 to 10	46 cc	Pasture B	7
Oct 11 to 13	46 cc	Pasture C	3
Oct 14 to 19	46 c	Pastures E and F	6
Oct 20 to Dec 6	46 c	Pasture A	18
Dec 7 to Dec 31	46 c	Pasture B	55
		2011	
Jan 1 to Feb 28	46 c[y]	Pasture B	59
Mar	44 cc	Farmyard and corrals[y]	31
April to May 15	44cc[y]	Pastures E and F[y]	45
May 16 to Jun 5	44 cc + 1 b	Pasture D	21
Jun 6 to 9	44 cc + 1 b	Pasture G	4
Jun 10 to Jul 4	44 cc + 1 b	Pasture A	25
Jul 5 to Oct 10	44 cc + 1 b	Summer pasture	0
Oct 11 to Nov 1	44 cc + 1 b	Pastures B and C[v]	22
Nov 2 to 16	44 c + 1 b	Pastures A and B	15
Nov 17 to 21	42 c + 1 b + 8 h	Pasture A	5
Nov 22 to Dec 1[y]	42 c + 1 b + 8 h[y]	Pasture C[u]	10
Dec 2 to 31	42c + 1b +8h[y]	Pasture E & F[y]	30
		2012	
Jan 1 to Feb 28	48 cc + 1 b + 5 h	Pastures E and F	59
March	48 cc + 1 b + 5 h[y]	Farmyard and corrals[y]	31
April to May 4	48 cc + 1 b + 5 h[y]	Pasture E and F	34
May 5 to Jun 2	48 cc + 1 b + 5 h	Pasture D	29
Jun 3 to Jul 2	48 cc + 1 b + 5 h	Pasture A	30
Jul 3 to Oct 23	48 cc + 1 b + 5 h	Summer pasture	0
Oct 24 to Nov 1	48 cc + 1 b + 5 h	Pasture B	9
Nov 2 to 20	48 cc + 1 b + 5 h	Pasture C[t]	19
Nov 21 to Dec 31	48 c + 1 b + 5 h	Pasture C	41

[z] cc = cow-calf pairs, c = cows, b = bull, h = heifer.
[y] Estimated because data not available.
[x] Cattle grazed for 3 d in each of three paddocks in Pasture D on the south side of Indianfarm Creek.
[w] Cattle moved to the north side of Indianfarm Creek in Pasture D.
[v] Cattle bale grazed in the south portion of Pastures B and C
[u] Cattle bale grazed in the north portion of Pasture C.
[t] Cattle bale grazed in Pasture C.

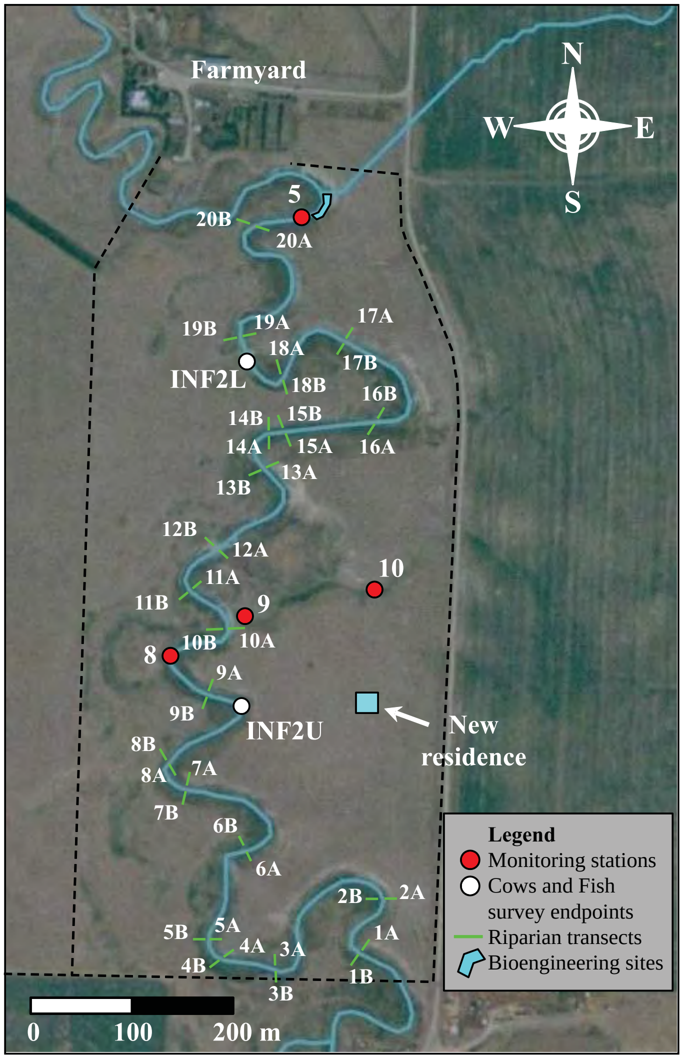

Figure 3.69. Location of the Cows and Fish riparian assessment endpoints, the annual riparian survey transects along Indianfarm Creek, and the water monitoring stations in Pasture A at the Pasture site.

Table 3.37. Riparian transect surveys carried out at the Pasture site from 2008 to 2012.

Survey date	Transects surveyed
June 4 and 5, 2008	1 to 20
June 10, 2009	6, 9, 12, 13, 16
July 6 and 7, 2010[z]	1, 2, 8, 11, 18
June 22, 2011	4, 7, 14, 17, 20
June 21, 22, and 28, 2012	1 to 20

[z] Transect 1 was assessed on June 11, 2010 and the surveys of the other transects were delayed until early July due to weather conditions.

Production cages were used to measure rangeland production in Pasture A each year. In 2008, 11 cages were installed; however, data from only 10 cages were used because one was knocked over by cattle. In subsequent years, 10 cages were used in the pasture (Figure 3.70). One cage was knocked over by cattle in 2009 and 2011 so only nine cages were harvested in these years. The cages were harvested in late September or during the first half of October. Detailed description of methods and analysis are in Sub-section 2.12.2.

3.7.2.5 Bioengineering

Bioengineering techniques were applied to an eroded bank of IFC at the PST site in an attempt to stabilize and reclaim the bank. A 100-m stretch along the east bank of IFC was selected near the north end of Pasture A (Figures 3.69 and 3.71). The stretch was highly erodible during high flows and rainfall runoff events, and it was affected by direct cattle access (i.e., pugmarks and cattle

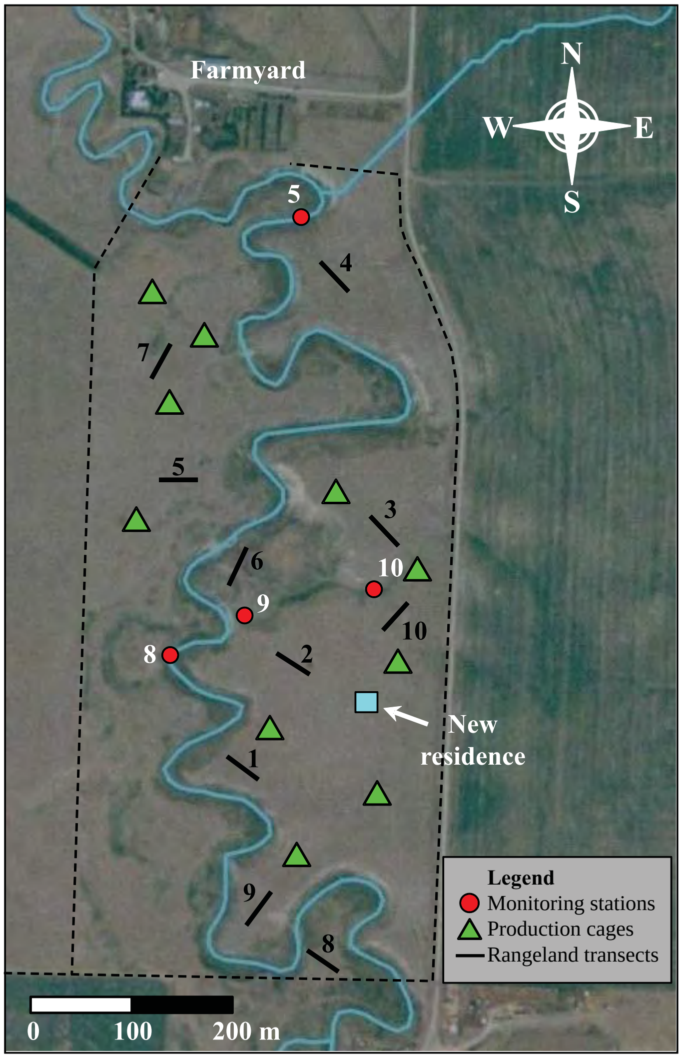

Figure 3.70. Location of the rangeland transects and approximate location of the production cages, used in Pasture A at the Pasture site.

trails). The bioengineering site was downstream of the monitored reach between Stations 5 and 8 in Pasture A (Figure 3.69). This meant it was not included in the BMP plan as it could not be assessed for effectiveness in terms of water quality. The site was bioengineered twice in 2010: once in April by ARD staff and the second time in November by a hired contractor.

Live stakes were collected in February and March 2010 from a watershed near Granum, Alberta for the April 2010 bioengineering construction. Sandbar willow, red osier dogwood (*Cornus stolonifera*), and balsam poplar (*Populus balsamifera*) were harvested for planting. Conventional structures (i.e., living materials) and unconventional structures (i.e., wood boards) were constructed at the site. These methods were chosen based on consultation with a contractor. The climate in this watershed can be dry and unpredictable at times and it was expected that these methods would provide the greatest chance of success for a site that had very little existing plant growth.

In April 2010, three wattle fences made out of wood boards were installed starting at low water level (Figure 3.71). To create the wattle fences, wood stakes (1.22 m long) were pounded into the slope as deep as possible and two boards were nailed vertically to the stakes along the length of the

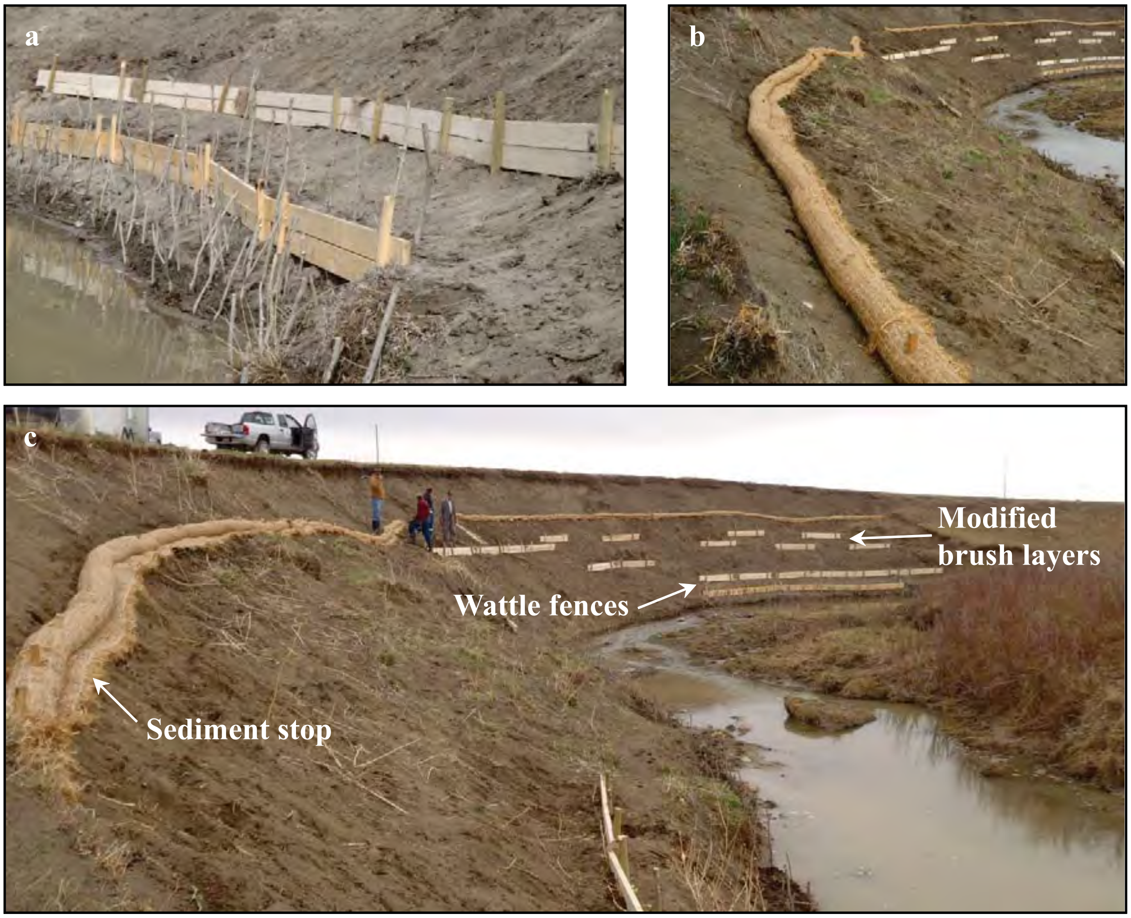

Figure 3.71. Bioengineering installation at the Pasture site showing (a) wattle fence, (b) sediment trap and modified brush layers, and (c) the whole bioengineered site on April 26 and 27, 2010.

fence. Soil was then back-filled onto the fence creating a 2:1 slope above the wattle fence. Approximately 400 live stakes were then planted in front and behind the fences (Figure 3.71a) using the same method described for the IMP site (Sub-section 3.5.2.4). Ten modified brush layers were constructed upslope of the wattle fences (Figure 3.71b,c). These brush layers were modified because they did not have live cuttings. Instead, wood boards were laid vertically across the slope and held with two wood stakes. Soil was then back-filled and packed behind the brush layer. These structures were used to slow the movement of soil and water down slope. Sediment stops were placed further upslope of the brush layers and were made of 100% bio-degradable coconut fiber and straw (Figure 3.71b,c). The sediment stops were rolled tightly and put on an area of the slope that was landscaped as flat as possible. Wood stakes (0.61 m long) were pounded directly into the rolls to hold them in place. Sediment stops were used to stop the movement of soil downslope and act as a filtration system by collecting sediment from water as it passed through the stop. A land reclamation seed mixture was spread on the entire site with a belly-grinder style grass seeder. The seed mixture contained 25% fleet meadow bromegrass (*Bromus biebersteinii*), 20% sheep fescue (*Festuca saximontana*), 15% slender wheatgrass (*Agropyron trachycaulum*), 15% western wheatgrass, 15% green needlegrass (*Stipa viridula*), and 10% carnival tall fescue (*Festuca arundinacea*).

Due to extensive damage of the April bioengineering installation caused by high precipitation and flows, new bioengineering structures were installed in November 2010. A contractor was hired to carry out this work. Live stakes of the same species used previously were obtained from near Beaver Mines, Alberta. Conventional bioengineering techniques were used, including one wattle fence at low water level and another fence further upslope (Figure 3.72). Both fences were approximately 1 m high and 70 to 90 m long. Unlike in April, these fences were constructed of all live materials, which were then back-filled with soil and reinforced with jute material and twine. Live stakes were planted in front and behind the wattle fences to ensure optimum stabilization of the soil. In addition, three rows of sediment stops were installed near the top portion of the slope and grass seed was dispersed over the entire area.

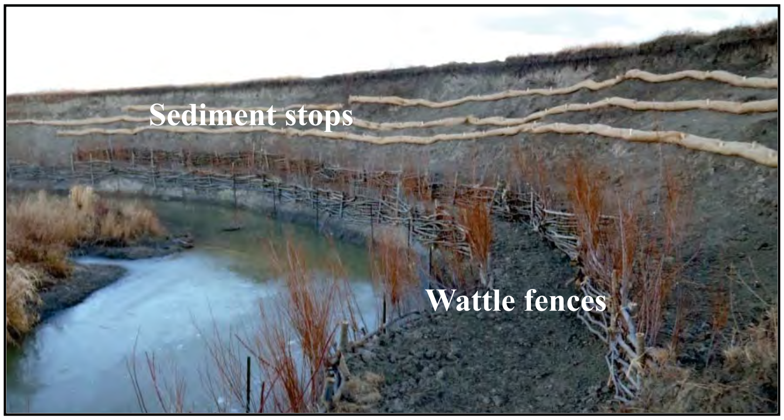

Figure 3.72. Bioengineering completed at the Pasture site in November 2010.

A fence constructed of steel t-bars and stucco wire was placed along the edge of the stream bank to protect the site from livestock and wildlife (e.g., beavers). As well, an electric fence was installed at the top of the slope to keep out livestock when they were in Pasture A. These fences were temporary. Survival counts of the live stakes were carried out in 2011 and 2012.

3.7.2.6 Soil Sampling

Soil characterization samples were collected (0 cm to 1.9 m) from three cores in the northern part of Pasture A and from three cores in the corral area. Soil agronomic samples (0 to 15 cm) were collected from 27 sampling points throughout the PST site in fall 2007, including Pastures A, B, C, D, E, and F. Soil agronomic samples were also collected from sampling points in the corral area. Details of soil sampling and analysis are in Sub-section 2.9.

In addition, three deep cores were sampled at the corrals to a depth of 3 m on October 23, 2009. Two of these deep cores (Cores 1 and 2) were collected from soil under the manure pack within the corrals and the third deep core (Core 3) was collected east of the corrals and manure pack from soil in the rangeland for comparison.

3.7.2.7 Water Flow and Quality

The PST site was monitored using four water monitoring stations (Figure 3.70). These included two instream stations on IFC (Stations 5 and 8), and two edge-of-field stations to monitor the contributions from the corral area (Stations 9 and 10). The corral area drained to the south into a shallow channel, which flowed into IFC. Station 10 was upstream of where the corral drainage entered the channel and Station 9 was downstream near where the drainage channel entered IFC. Automatic Isco water samplers were installed at all four monitoring stations and Level TROLLs monitored water height at Stations 5 and 8. Circular flumes were installed at Stations 9 and 10. When flow was detected at Station 9, sampling of Station 9 as well as at Stations 5, 8, and 10 was triggered.

Five event types were defined for Stations 5 and 8: snowmelt, rainfall, base flow, dam release, and flood. Base flow was generally low flow when no overland runoff was occurring, as confirmed by hydrographs, climate data, and field observations. Dam release events occurred when water was released from Therriault Dam. This sometimes occurred to make room for spring snowmelt or to provide water for livestock later in summer. The water quality data collected during the dam releases were similar to base-flow data, and therefore, dam releases were combined with the base-flow events for statistical comparisons. The flows during the flood on June 17, 2010 were higher than any flows that occurred throughout the study and data from these flood events were not included in statistical analysis. This was because data for pre- and post-BMP periods needed to have similar flow ranges when making statistical comparisons (Spooner et al. 1985) and also because agricultural BMPs are not designed for or effective during extremely high-flow conditions.

The water quality data from Stations 5 and 8 were statistically analyzed as upstream-downstream stations to assess BMP effects as described in Sub-section 2.8.4. Stations 9 and 10 were used to monitor the drainage from the corral area and both were referred to as edge-of-field sites relative to IFC. However, data from these two stations were also analyzed as upstream-downstream stations, unto themselves. Rainfall runoff event type was not statistically analyzed for Stations 9 and 10 because only two water samples were collected during the pre-BMP period.

Further details on water monitoring stations, sampling, flow measurements, laboratory analysis, and statistical analysis are presented in Section 2.

3.7.3 Results and Discussion

3.7.3.1 Implementation of Beneficial Management Practices

The rotational grazing plan implemented at this site worked well from a management perspective. The cattle were successfully moved through all pastures more equally allowing for periods for rest and vegetative recovery. The provision of off-stream watering allowed for exclusion of cattle from Pastures A, D, and G while other pastures were being utilized. Previously, access was needed to these pastures so livestock could obtain water (i.e., IFC). During the post-BMP period, cattle spent up to 70% less time in Pasture A. This is a maximum value as it assumes full access to Pasture A whenever cattle were at the PST site during the pre-BMP period. Although the management data are not detailed enough to be more specific, Pasture A was heavily utilized in the pre-period. The exclusion during the post-BMP period ensured better utilization of the other pastures and allowed for a period of rest and regrowth for riparian pastures (i.e., Pastures A, D, and G), as well as other pastures (i.e., Pastures B, C, E, and F). Range health scores indicated Pasture A was overgrazed in the pre-period, and this rest period was important for rangeland and riparian recovery.

Based on Arychuk (2009), a 64-d (Table 3.35) carrying capacity for a pasture the size of Pasture A in fair to poor condition in this region was estimated at 23 to 35 cow-calf pairs for small cows or 15 to 23 cow-calf pairs for large cows. This means that Pasture A was overstocked prior to implementation of the rotational grazing BMP plan. During the post-BMP period, the average grazing period in Pasture A was reduced to 37 d yr^{-1} (Table 3.36). The carrying capacity for a 37-d period was estimated at 40 to 61 cow-calf pairs for small cows or 27 to 41 cow-calf pairs for large cows. Therefore, during the post-BMP period, the number of animals in Pasture A better matched the estimated carrying capacity. However, the pasture may still have been overstocked depending on animal size and annual variation of pasture condition. The smaller average herd size during the post-BMP period (Table 3.36) compared to the pre-BMP period (Table 3.35) also contributed to reduced grazing pressure.

When the cattle grazed in Pasture A after BMP implementation, they had access to IFC as well as the new off-stream watering system. The producer observed that cattle in Pasture A often crossed the creek and walked to the trough (140 m to the west of the creek) to drink (Figure 3.65). The producer was satisfied with the off-stream watering system designed to reduce direct access by the cattle to the creek. In some areas of the pasture, the producer noticed more vegetation along the creek banks. The producer liked that the off-stream watering system allowed independent grazing of Pastures B and C, and reduced grazing pressure on Pasture A.

The use of electric fences to rotate cattle through the three paddocks in Pasture D allowed the cattle to graze old pasture growth and controlled the spread of pasture weeds. However, the producer commented that since no off-stream water was available in these paddocks, the cattle likely spent more time in the creek than was desirable.

The total cost of the BMP implementation at the PST site was about $17,000 (Table 3.38) with the majority (85%) of this cost being for the off-stream watering system. The remainder was for windbreaks and some electric fences. All of these costs were one-time expenses to purchase and implement. Future costs will likely be required for routine maintenance and repairs. Bioengineering at this site cost close to $24,000 (Table 3.39).

The demolition of the corrals monetarily did not cost anything, however, more than 40 h of labour were required to dismantle and remove the corrals from the area. There were some minor costs, such as fuel for vehicles that were unaccounted for. The corrals were constructed of wooden planks, which were well weathered and salvaged by the producer, with potential value as art material.

Table 3.38. Cost of beneficial management practices at the Pasture site.

Year	Item	Material Cost ($)	Labour (h)
2009	Permanent windbreak fence	495	45
	Portable windbreak fence	1,250	
	Demolition of old corral	-	42
	Water-line PVC pipe	885	
	Water-trough	600	
	Electric cable	3,343	
	Hydrovac	240	
	Trenching	8,560	
	Concrete pad	500	
	Trough installation	-	60
	Sub-total	**15,873**	**147**
2010	Electric fence[z] – paddocks	770	1
	Sub-total	**770**	**1**
	Grand total	**16,643**	**148**

[z] Included controller, posts, wire, solar panel, and battery.

Table 3.39. Cost of Bioengineering at the Pasture site in 2010.		
Item	Cost ($)	Labour (h)
Bioengineering	23,043[z]	200[y]
Electric fence[x]	473	2
Total	**23,516**	**202**

[z] Contracted cost of November 2010 installation.
[y] Manpower for April 2010 installation.
[x] Included controller, posts, wire, plastic insulators, ground-rods, and ground-rod clamps.

3.7.3.2 Riparian Quality

Cows and Fish assessment. Riparian quality improved at the PST site (i.e., Pasture A) from 2007 to 2012. The overall riparian health rating increased from 42% in 2007 to 63% in 2012, suggesting a positive effect by the implemented BMPs (Table 3.40). The rating in 2012 was only slightly less than the provincial average of 69%, which is based on 2059 sites, on 440 water bodies in Alberta from 1997 to 2010. Improvement was observed for the vegetation and soil/hydrology factors. Riparian function rating increased from unhealthy in 2007 (<60%) to healthy but with problems in 2012 (60 to 79%). There was an increase in shrubs, particularly sandbar willow, and grasses, particularly smooth brome. The increase in sandbar willow (Figure 3.73), as well as the establishment of choke cherry (*Prunus virginiana*), saskatoon (*Amelanchier alnifolia*), and false mountain willow (*Salix pseudomonticola*), suggest that excellent regeneration occurred. Although, smooth brome is not a desired species for riparian areas, it can reduce bare ground and help minimize soil erosion. There was a decrease in browsing pressure, as well as a decrease in human-caused bare ground and physical alterations along stream banks. Trace amounts of invasive plant species were found at this site in 2007 and 2012, with a slight increase in Canada thistle (*Cirsium arvense*) abundance and distribution in 2012.

The implementation of the rotational grazing plan for 3 yr post-BMP resulted in the improvement of riparian health in Pasture A. This improvement can be attributed to the rotational grazing plan that reduced grazing pressure and allowed for periods of rest. The Cows and Fish report further suggested limiting access through the typically high precipitation time of early June to reduce damage of saturated stream banks by cattle.

Table 3.40. Summary of the Cows and Fish riparian health assessment carried out at the Pasture (PST) site on June 12, 2007 and June 12, 2012.

	2007 assessment			2012 assessment			
	PST site	Max. score	Rating (%)[z, y]	PST site	Max. score	Rating (%)[z, y]	Health difference
Vegetation							
Vegetative cover of site	4	6		6	6		improved
Invasive plant species (cover)	2	3		1	3		declined
Invasive plant species (density distribution)	0	3		0	3		no change
Disturbance-caused undesirable herbaceous species	1	3		0	3		declined
Preferred tree and shrub establishment and regeneration	6	6		6	6		no change
Utilization of preferred trees and shrubs	0	3		2	3		improved
Live woody vegetation removal by other than browsing	na[x]	na		3	3		na
Decadent and dead woody material	3	3		3	3		no change
Vegetation rating	16	27	59	21	30	70	improved
Soil/hydrology							
Streambank root mass protection	0	6		2	6		improved
Human-caused bare ground	2	6		6	6		improved
Streambank structurally altered	0	6		2	6		improved
Human physical alteration to site	0	3		1	3		improved
Stream channel incisement	6	9		6	9		no change
Soil/hydrology rating	8	30	27	17	30	57	improved
Overall rating	24	57	42	38	60	63	improved

[z] Site score as a percentage of the maximum possible score.
[y] Healthy (80 to100%): Little or no impairment to riparian functions.
Healthy but with problems (60 to 79%): Some impairment to riparian functions due to human or natural causes.
Unhealthy (<60%): Impairment to many riparian functions due to human or natural causes.
[x] na = not available.

Figure 3.73. Sandbar willows improved in distribution at the Pasture site.

Transect assessment. For plots at the Pasture site, a one-way PERMANOVA test showed that overall, communities were significantly different in at least two year-zone combinations. Pairwise comparisons between groups showed that communities were significantly different between 2008 and 2012 in both the riparian and transition zones, but not in the upland zone (Table 3.41). Species difference tables are in Appendix 5. For upland plots at the PST site, community differences, although not statistically significant, were mostly attributable to (in order of importance from most to least, for those species whose contribution to overall difference was greater than 4%) an increase in percent cover of smooth brome, Kentucky bluegrass, prickly wild rose, and western snowberry, and a decrease percent cover of western wheatgrass and green needlegrass. Community differences in the transition plots were mostly attributable to increases in smooth brome, Kentucky bluegrass, prickly rose, and western snowberry, and a decrease in quackgrass. For riparian plots, community differences were mostly attributable to increases in smooth brome, Kentucky bluegrass, prickly rose, and western snowberry, and decreases in willow, sedge, and quackgrass.

Zone, year, and their interaction were significant factors in the analysis of SR and ED (Table 3.42). In the analysis of E, the interaction term was not significant, and was removed. In the final model, which included year and zone, neither of these factors were significant, indicating that E was consistent among years and zones. For all vegetation zones, SR and ED were significantly greater in 2012 (post-BMP) compared to 2008 (pre-BMP).

Generally, there were more vegetative species observed in 2012 than in 2008 at the PST site, particularly in the upland and riparian zones (Appendix 5). A total of 22 species not identified in 2008 were recorded at the PST site in 2012. These included native forbs and desirable riparian species [e.g., stiff yellow paintbrush (*Castilleja lutescens*), wild-blue flax (*Linum lewisii*), bergamot (*Monarda fistulosa*), blue-eyed grass (*Sisyrinchium montanum*), hemp-nettle (*Galeopsis tetrahit*)]. Balsam poplar was also found on two transects upstream of the PST bioengineering site. This indicates that this highly desirable riparian tree, not present in 2008, may have begun to re-establish at the site (native balsam poplars are growing along IFC in several locations upstream). Another establishment theory is that some live-staking material washed down from the WIN

Table 3.41. Analysis of differences in the overall plant communities (percent cover) between year (i.e., before and after BMP implementation) and vegetation zone combinations at the Pasture site. [z]

Overall model

Source	Sum of squares	F	*P*
Year×Zone	91.26	12.74	0.0001
Total	106.6		

Differences between Year×Zone combinations
Bonferroni-corrected P values

	2008 Upland	2008 Transition	2008 Riparian	2012 Upland	2012 Transition	2012 Riparian
2008 Upland	-	0.006	0.002	1.000	0.002	0.002
2008 Transition		-	0.002	0.006	0.002	0.002
2008 Riparian			-	0.002	0.002	0.002
2012 Upland				-	0.429	0.017
2012 Transition					-	0.002
2012 Riparian						-

[z] One-way PERMANOVA statistical test .

Table 3.42. Type 3 tests of fixed effects (year, zone) in the analysis of species richness (SR), effective diversity (ED), and evenness (E) at the Pasture site.[z]

Parameter	Effect	Zone	Year	LSM[y,x]
SR	Year × Zone	Riparian	2008	4.5*a*
			2012	9.4*b*
		Transition	2008	6.1*a*
			2012	8.5*b*
		Upland	2008	7.8*a*
			2012	12.3*b*
ED	Year × Zone	Riparian	2008	3.2*a*
			2012	6.1*b*
		Transition	2008	3.9*a*
			2012	5.5*b*
		Upland	2008	5.0*a*
			2012	7.3*b*
E	Year			ns[w]
	Zone			ns
	Year × Zone			ns

[z] Generalized linear model (with a Poisson error distribution and log link function) used rather than a general linear model.
[y] LSM = least square means.
[x] Means for a give parameter and zone (i.e., 2008 vs. 2012) followed by the same letter are not significantly different ($P < 0.1$).
[w] ns = not significant.

bioengineering sites about 1.4 km upstream and may have taken root at the PST site after high-flow events. Whatever the origin, the presence of this species is good for the site as balsam poplars have deep stabilizing root systems, provide critical shelter and habitat for wildlife and livestock, and can colonize newly deposited sediment areas with seeds and root generation (Hale et al. 2005).

Similar to the IMP site (Sub-section 3.5.3.2), the SR and ED increased from 2008 to 2012; however, these increases were mostly due to invader species such as smooth brome and Kentucky bluegrass. There were increases in a couple of desirable shrub species, such as prickly wild rose and western snowberry in all three zones. The decrease in quackgrass in the transition and riparian zones was a positive change because it is an invader species; however, there was also a decrease in the desirable western wheatgrass (upland zone). There was a decrease in willow species cover in the riparian zone, which was in contrast to the final Cows and Fish assessment that indicated an increase in sandbar willow. This difference may have been due to stream bank erosion caused by extremely high flows in 2010 and 2011 at the localized area of the quadrants. The IMP and PST riparian areas were possibly in the first stages of ecological succession and may require further time for the establishment of more desirable species typical of a healthy riparian area. Unlike the IMP site, the PST site was not subject to livestock exclusion, but rather, a rotational grazing plan. Because of the increases in SR and ED and the improved Cows and Fish assessment ratings in 2012, it is recommended that rotational grazing continue at this site.

3.7.3.3 Rangeland Quality Assessment and Cage Production

Foliar cover in the pre-BMP period (2007 to 2009) at the PST site was dominated by the non-native invader Kentucky bluegrass, with an average of 19% ground cover (Table 3.43). Other dominant grasses in the pre-BMP period included smooth brome and green needle grass. In the post-BMP period (2010 to 2012), the pasture was still dominated by Kentucky bluegrass, which averaged 42% of ground cover. The increased percent cover of Kentucky bluegrass was likely related to weather conditions, as the post-BMP period was wetter than the pre-BMP period. Other dominant grasses in the post-BMP period included western wheatgrass and awned wheatgrass (*Agropyron subsecundum*). There was a positive increase in foothills rough fescue (*Festuca campestris*) during the post-BMP period, with the highest percent cover in 2012. For this ecoregion, the dominant foliar cover of the reference plant community should be foothills rough fescue at 36%, Idaho fescue (*Festuca idahoensis*) at 12%, and sedges at 9% (Adams et al. 2003). During the pre-BMP period, foothills rough fescue was non-existent throughout the pasture, likely because of long-term overgrazing. The increase in foothills rough fescue may suggest the rotational grazing plan reduced grazing pressure, allowing the pasture to regain some natural plant vigor.

Table 3.43. Average (n = 10) percent cover of grasses at the Pasture site during the pre-BMP and post-BMP years.

		----- pre-BMP -----			----- post-BMP -----			Grazing	Forage
Grass species		2007[z]	2008	2009	2010	2011	2012	response[y]	value[x]
northern wheatgrass	*Agropyron dasystachyum*	14.10	0.59	7.26	7.51	0.99	0.37	I	G
slender wheatgrass	*Agropyron trachycaulum*	1.17						I	G
smooth brome	*Bromus inermis*	16.17	10.12	8.09	2.64	0.64	0.37	EIV	G
sedge species	*Carex (spp.)*	3.97	7.90	5.81	2.82	0.81		D	G
foothills rough fescue	*Festuca campestris*	3.28	0.12			0.95	9.60	D	G
June grass	*Koeleria macrantha*	0.95	5.90	0.88	0.44	0.60	2.04	I	G
Canada bluegrass	*Poa compressa*	1.17	0.12					EIV	G
Kentucky bluegrass	*Poa pratensis*	22.05	21.10	14.37	34.89	48.71	43.08	EIV	G
needle and thread	*Stipa comata*	0.03	1.10	0.61				D	G
green needle grass	*Stipa viridula*	7.77	8.10	9.62	0.46	1.30	3.62	D	G
western wheatgrass	*Agropyron smithii*		13.71		12.73	10.12	15.09	I	G
quackgrass	*Agropyron repens*		0.45	1.60	1.07	7.60	0.49	EIV	G
prairie muhly	*Muhlenbergia cuspidata*		0.31	0.41				I	F
foxtail barley	*Hordeum jubatum*			0.10				IV	P
pine grass	*Calamagrostis rubescens*				1.53	0.39	1.08	I	F
blue grama	*Bouteloua gracilis*				0.87			I	G
awned wheatgrass	*Agropyron subsecundum*					0.53	10.51	D	G
sheep fescue	*Festuca saximontana*					0.12		D	G
western porcupine grass	*Stipa curtiseta*						1.29	D	G
timothy	*Phleum pratense*						0.03	EIV	G
	Total average grasses	71	70	49	65	73	88		

[z] In 2007, only six transects were assessed. From 2008 to 2012, four more transects were added for a total of 10 transects per year
[y] Grazing response: D = decreaser; I = increaser; IV = invader; EIV = exotic invader.
[x] Forage value: G = good; F = fair; P = poor.

The total average percent grasses in the rangeland transects increased after BMP implementation in 2010, with the highest percentage of grass cover in 2012 (Figure 3.74). Average percent grass cover increased about 19% from the pre- to the post-BMP period (Table 3.43). During the pre-BMP period, fringed sage (*Artemis frigida*) was the dominant herbaceous (i.e., forb/boardleaf) species and continued to be dominant in the post-BMP period (Table 3.44). Aster species, low everlasting (*Antennaria aprica*), and tufted fleabane (*Erigeron caespitosus*) were also dominant forbs in the post-BMP period. These forb species are not preferred forage for livestock and tend to be indicators of overgrazing. However, the number of forb species increased from 12 in the pre-BMP period to 29 in the post-BMP period. This showed an increase in species diversity with most species native to the ecoregion. Decreaser forbs (e.g., sticky purple geranium) were found in 2012. A decreaser means the species decreases in response to grazing, and therefore, an increase in presence is positive for the recovery of an overgrazed pasture. Total average forb cover was similar between the pre-BMP period (23%) and the post-BMP period (20%) (Table 3.44).

In the pre- and post-BMP periods, western snowberry and prickly wild rose were the only shrubs identified, with less than 5% cover among the years (Table 3.45). There was a slight increase in average percent cover from 0.5% in the pre-BMP period to 2% in the post-BMP period. This increase may be indicative of the reduced grazing pressure and/or due to climatic factors. Shrub communities in the Foothills Fescue Ecoregion are limited to riparian areas and sheltered areas due to summer aridity and frequent winter Chinook winds (Adams et al. 2003). Therefore, it is common to have little (<25%) to no cover of shrubs in pastures in this region and this was true for the PST site.

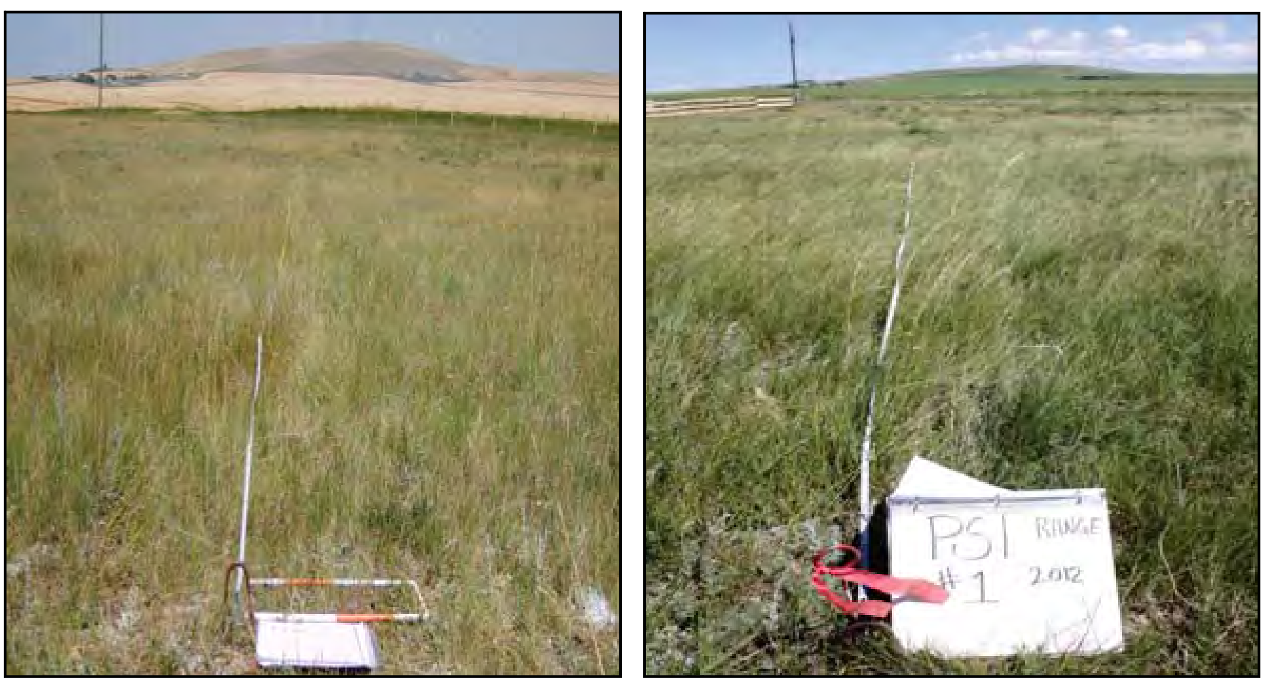

Figure 3.74. Transect 1 in Pasture A (a) in 2007 (pre-BMP) and (b) showing increased vegetation cover in 2012 (post-BMP).

Table 3.44. Average (n = 10) percent cover of forbs at the Pasture site during the pre-BMP and post-BMP years.

Forbs		----- pre-BMP -----			---- post-BMP ----			Grazing	Forage
		2007[z]	2008	2009	2010	2011	2012	reponse[y]	value[x]
yarrow	*Achillea millefolium*	1.00	0.78	2.46	0.65	0.56	0.86	I	P
pasture sage	*Artemesia frigida*	4.93	4.80	5.37	6.51	4.95	6.14	I	P-F
prairie sage	*Artemesia ludoviciana*	1.77	1.10	0.50	0.06	0.41	1.07	I	P-F
aster species	*Aster (spp.)*	4.55	5.68	2.89	6.61	3.97	0.94	I	F
milkvetch	*Astragalus (spp.)*	0.38	0.10	0.16		1.87		I	POIS
low everlasting	*Antennaria aprica*	4.48	4.90	3.75	1.80	1.57	2.86	I-IV	P
three-flowered aven	*Geum triflorum*	0.10	0.15	0.94	0.98	0.04	0.17	I	P
silverleaf psoralea	*Psoralea agrophylla*	0.22	0.11	0.17	0.03		0.27	I	P
prairie cinquefoil	*Potentialla pensylvania*	1.37	1.07	0.53	0.32	0.72	1.02	I	P
moss phlox	*Phlox hoodsii*	0.95	1.11	1.00	2.05	0.31	0.59	I	P
goldenrod	*Solidago (spp.)*	1.72	0.17	0.21	0.07	1.74	0.86	I	P
scarlet mallow	*Sphaeralcea coccinea*	0.30	0.66	0.71	0.60	0.49	0.01	I	P
stinkweed	*Thlapsi arvense*	0.18		0.22	0.07	0.17	0.03	I	P
dandelion	*Taraxacum officin ale*		0.03	0.05	0.03	0.06	0.06	EIV	F
vetch	*Vicia americana*		0.33	0.11	0.46		1.02	D	G
tufted fleabane	*Erigeron caespitosus*		2.83	1.60		0.64	2.11	I	P
early yellow locoweed	*Oxytropis sericea*		0.04	0.04		0.01	0.11	I	POIS
shining arnica	*Arnica (sp.)*		0.03					I	P
goatsbeard	*Tragopogon dubius*		0.01				0.01	EIV	P
clover	*Trifolium pratense*		0.03					EIV	G
flixweed	*Descurainia sophia*		0.02					EIV	P
fuzzy-tongue penstemon	*Penstemon eriantherus*		0.10	0.02				I	F
woolly cinquefoil	*Potentilla hippiana*		0.80	0.19				I	P
perennial sowthistle	*Sonchus arvense*				0.01			EIV	F
lamb's quarters	*Chenopodium album*			0.05	0.05			EIV	P
wild mustard	*Brassica kaber*				0.04			EIV	POIS
purple prairie clover	*Petalostemon purpureum*				0.14			D	F
blue-eyed grass	*Sisyrinchium montanum*					0.01		I	F
dotted-blazing star	*Liatris punctata*					0.24		D	F
wild flax	*Linum lewisii*					0.01	0.01	I	F
scarlet gaura	*Gaura coccinea*			0.03		0.20	0.03	I	P
black medick	*Medicago lupulina*					1.00	0.05	EIV	P
gumweed	*Grindellia squarrosa*						0.09	I-IV	P
yellow paintbrush	*Castilleja occidentalis*						0.03	I	P
cut-leaved anemone	*Anemone multifida*						0.03	I	P
northern bedstraw	*Galium boreale*						0.94	I	G
prairie coneflower	*Ratibida columnifera*						0.10	I	P
wild bergamot	*Monarda fistulos a*						0.01	D	P
yellow puccoon	*Hydrastis canadensis*						0.07	I	P
pygmy flower	*Androsace septentrionalis*						0.01	I	F
sticky purple geranium	*Geranium viscosissimum*						0.01	D	G
	Total average forbs	22	25	21	20	19	20		

[z] In 2007, only six transects were assessed. From 2008 to 2012, four more transects were added on for a total of 10 transects per year.
[y] Grazing response: D = decreaser; I = increaser; IV = invader; EIV = exotic invader.
[x] Forage value: G = good; F = fair; P = poor; POIS = poisonous.

Table 3.45. Average (n = 10) percent cover of shrubs and other cover at the Pasture site during the pre-BMP and post-BMP years.

Shrubs and other cover		----- pre-BMP -----			---- post-BMP ----			Grazing	Forage
		2007[z]	2008	2009	2010	2011	2012	reponse[y]	value[x]
prickly wild rose	*Rosa acicularis*	0.30	0.18	0.27	1.87	0.52	1.13	I	P
western snowberry	*Symphoricarpos occidentalis*	0.17	0.18	0.37	2.29	0.48	0.24	I	p
	Total average shrubs	0.47	0.36	0.64	4.16	1.00	1.37		
Total litter		26	24	22	61	90	96		
Total bare ground		2	2	3	9	4	3		
Total moss		11	6	8	2	3	4		
Total vegetation		92	85	93	88	88	91		

[z] In 2007, only six transects were assessed. From 2008 to 2012, four more transects were added on for a total of 10 transects per year.
[y] Grazing response: D = decreaser; I = increaser; IV = invader; EIV = exotic invader.
[x] Forage value: G = good; F = fair; P = poor.

Average total bare ground cover varied little from year to year, and was less than 5% for most years (Table 3.45). The percent cover of moss was consistently less in the post-BMP period (3% average) compared to the pre-BMP period (8% average), and the decrease in percent cover was likely due to the increase of the litter cover. The litter layer increased substantially from 24% cover in the pre-BMP period to 82% cover in the post-BMP period. The increase in litter cover indicates a positive change. A healthy pasture in the Foothills Fescue region should have at least 50% litter mass and this was exceeded in all three post-BMP years. In contrast, average total vegetation percent cover was essentially the same between the pre- and post-BMP periods.

The average grassland range health scores ranged from 47 to 74% (Table 3.46). The pre-BMP years had lower health scores compared to the post-BMP years. The average was 51% for the pre-BMP period compared to 70% for the post-BMP period. The grassland range health score was unhealthly (<50%) in 2008, and healthy with problems in the other years. Even though the score was healthy with problems throughout the post-BMP period, the health scores increased with time, and nearly reached the healthy category (i.e., 74%) in 2012. Pastures in the category of healthy with problems need to be watched carefully and require further management. The BMPs implemented at this site improved rangeland health, and with additional years of similar management, the pasture should continue to recover. However, in rough fescue grasslands that are invaded by agronomic grasses such as Kentucky bluegrass, recovery may be limited and a rating of healthy with problems may be the maximum recovery attainable (Adams et al. 2009).

Dry-matter yields of grass, forb, and litter were generally higher inside the production cages compared to outside the cages (Table 3.47). For example, the average grass yield from 2008 to 2012 was 1624 kg ha^{-1} inside the cage and 965 kg ha^{-1} outside the cage. Grass yield outside of the cages averaged 919 kg ha^{-1} for the pre-BMP period (2008 and 2009) and 996 kg ha^{-1} for the post-BMP period (2010 and 2012). Grass yield in 2010 and 2011 was less than in 2008 and 2009, and greatest in 2012. Forb yields were more sporadic throughout the years at the PST site.

Table 3.46. Grassland range health score percentages for the Pasture site in the pre-BMP period (2007 to 2009) and the post-BMP period (2010 to 2012).

	Transect number										
	1	2	3	4	5	6	7	8	9	10	Average[z]
Year	-- (%)[y] --										
2007	58	58	55	42	72	38	na[x]	na	na	na	54
2008	45	45	48	42	48	20	48	48	62	58	47
2009	na[w]	na	na	na	na	na	na	na	na	na	-
2010	55	60	80	55	70	70	67	70	60	58	65
2011	70	70	73	70	73	53	70	73	73	73	70
2012	70	70	83	83	70	67	83	73	73	70	74

[z] Health ratings: healthy = 75 to 100%; healthy with problems = 50 to 74%; unhealthy < 50%.
[y] Summation of five health scores (i.e., ecological status, community structure, litter cover and distribution, erosion and bare soil, and noxious weeds) calculated as a percentage of a maximum score of 60 (Adams et al. 2005).
[x] Not sampled.
[w] Missing data.

Table 3.47. Production cage harvest average dry-matter weight for grass, forbs, and litter at the Pasture site.

	pre-BMP		post-BMP		
	2008 (n = 10)	2009 (n = 9)	2010 (n = 10)	2011 (n = 9)	2012 (n = 10)
Sample	------------------------	------------ ($kg\ ha^{-1}$)	------------	------------	------------------------
			Grass		
Inside cage	1041	2679	852	1547	2001
Outside cage	845	992	704	727	1558
Difference[z]	*196c*	*1686a*	*148c*	*821b*	*443bc*
			Forb		
Inside cage	198	392	199	496	330
Outside cage	295	357	128	265	321
Difference	*-97b*	*35ab*	*71ab*	*231a*	*8b*
			Litter		
Inside cage	161	615	52	1116	812
Outside cage	123	97	55	602	713
Difference	*38b*	*518a*	*-3b*	*514a*	*99ab*

[z] Average annual inside-outside yield differences followed by letters are significantly different at $P < 0.1$.

The average amount of litter inside the cages ranged from 52 to 1116 kg ha^{-1}. The presence of litter is important for native grassland to protect the soil surface and help conserve moisture (Adams et al. 2009). Healthy grasslands in this region (i.e., Fescue Foothills) should have 874 to 1345 kg ha^{-1} litter (Adams et al. 2009). During the pre-BMP period (2008 and 2009), the amount of litter inside and outside of the cages was well below the range of litter mass for a healthy pasture. During the post-BMP period (2011 and 2012), litter dry matter inside the cages was within the healthy threshold range. Even through the amount of litter outside of the cages was less than the desired healthy range, the dry-matter amounts were higher than in 2008 and 2009. It is unknown why dry matter in 2010 was lower compared to the other years. However, including 2010, litter dry-matter yield outside the cages was about four-fold greater for the post-BMP period compared to pre-BMP period. This increase in litter suggests improved pasture health due to reduced pressure by cattle grazing.

Annual grass and litter dry-matter yield differences between the inside and outside of the cages were significantly larger (Table 3.47) when preceded by years with greater than 30-yr normal precipitation (Sub-section 3.2). This suggests there was a lag time between the vegetative responses to moisture in 2009 and 2011, which were also the years with the highest grass and litter yields. The largest differences in grass and litter inside and outside of the cages occurred in 2009, as 2008 had greater than normal precipitation (628 mm) and no reduced grazing pressure. The next largest grass and litter differences occurred in 2011, which was also preceded by a greater than normal precipitation year, as 2010 had the greatest amount (679 mm) of all the study years. However, the differences in grass yields between inside and outside the cages were smaller in 2011 than in 2009, and this suggests that a combination of climatic effects and reduced grazing pressure was likely the cause. Interestingly, 2012 had the highest grass and litter yields outside the cages, and therefore, smaller differences between inside and outside of the cages, as it was preceded by 2 yr of greater than normal precipitation (2011 had 559 mm) and two and a half years of reduced grazing pressure.

3.7.3.4 Bioengineering

The IFC watershed received high precipitation during the springs of 2010 and 2011 (Sub-section 3.2.2). This created high creek flows and saturated soils, which were detrimental to the bioengineering installations. The first bioengineering installation was completed in April 2010 (Figure 3.71c). Then 60 mm of rain fell in late April, 110 mm in 5 d at the end of May, and 126 mm in 2 d during mid-June. Although the structures were repaired several times during this period, the rainfall event in June washed away most of the structures (Figure 3.75).

The bioengineering installation that was done in November 2010 (Figure 3.76a), was badly damaged and washed away by flowing water in spring 2011 (Figure 3.76b). Some initial damage was caused by spring flows but following repairs, there was some establishment of willows and grass. However, high-flow events in May and June eventually washed away most of the structures, leaving only a modified brush layer, one sediment stop, and a few live cuttings. The number of live stakes that remained after the damage was 69 willows and 10 poplars on September 13, 2011. Although, the contractor did not provide the number of live stakes planted the second time, it can be assumed to be similar to the first installation (i.e., 400) and this represented about a 20%

survival rate. A second count conducted on July 18, 2012 showed 53 willows and 5 poplars were present, which represents a survival rate of 74% from September 2011. Although the majority of the bioengineering structures were lost, at least some of the live stakes were able to establish at the site. Willows reproduce by suckering from their roots, and if they continue to survive, it is expected that they will spread along the stream bank and help stabilize the bank.

The application of bioengineering techniques at this site was high risk in terms of success. The site was highly unstable with steep banks on the outside of a sharp bend in the creek. Unfortunately, major precipitation and flow events occurred shortly after the bioengineering structures were installed. Perhaps if flow in the creek was normal or below normal for a couple of years, the live stakes and grass would have had a chance to establish and better resisted the effects of high flow conditions. This reach is highly erosive naturally, and the presence of cattle has contributed to the erosion processes. The cost of the contracted bioengineering installation was about $23,500, and as a result, we do not recommend landowners pursue such major bioengineering projects for small, highly unstable reaches of creek. More feasible, may be to focus

Figure 3.75. Damage to the bioengineering structures installed in April 2010. The dotted line shows approximately the high water level during peak flow.

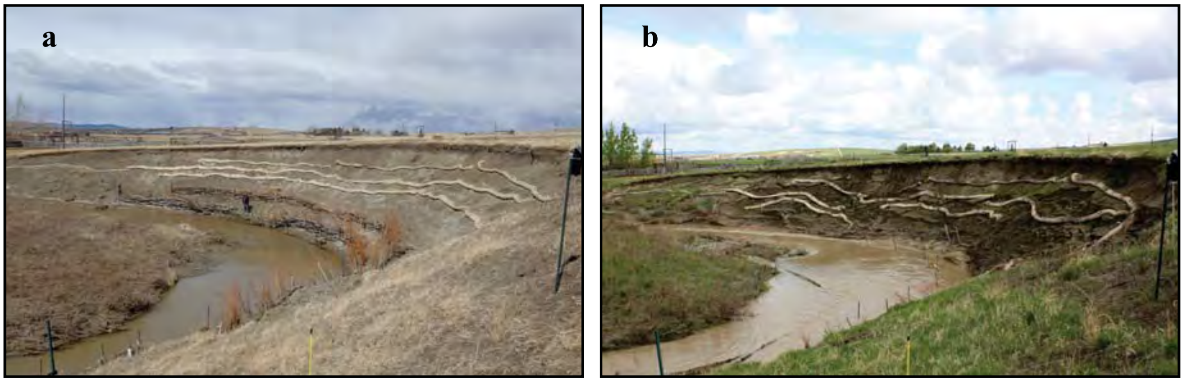

Figure 3.76. The second bioengineering installation on (a) April 28, 2011 before high water flow in Indianfarm Creek and on (b) May 30, 2011 showing damage caused by high flows at the Pasture site.

on less risky, small-scale projects that may be initiated by landowners with help from neighbours and/or a local watershed group. Live staking was the most successful part of this bioengineering project and if landowners along a creek can achieve even 5 to 10% survival rates may help stabilize stream banks.

3.7.3.5 Soil

The average concentration of extractable NO_3-N, NH_4-N, STP in the top 15 cm of soil was not excessive at the PST site (Table 3.48). At the corral area, NO_3-N concentration in the top 15 cm of soil was twice as high as the rest of the PST site, but still relatively low. Ammonium N concentration was similar at the corral area compared to the rest of the PST site. However, STP concentration was nearly 10-fold higher at the corral area compared to the rest of PST site. This was likely because of the high density of fecal pats deposited near the corrals (Figure 3.67b). The average STP concentration at the corral area was above the agronomic threshold of 60 mg ka^{-1}, which is generally the concentration at which annual crops will no longer respond to added P (Howard 2006). No phosphorus fertilizer is recommended for grass in the Black Soil Zone when STP in the top 60 cm of soil is greater than 90 kg ha^{-1} (McKenzie 2005). If we assume that 75% of this threshold level was in the top 15 cm of soil, the STP concentration would be about 37.5 mg kg^{-1}, which is nearly three-fold less than the measured concentration at the corral area. Accumulated STP greater than agronomic thresholds will increase the degree of P saturation and increase the risk of P loss in surface runoff (Casson et al. 2006).

Of the two deep soil cores drilled under the manure pack in the corrals, Core 1 had high concentrations of NO_3-N throughout the 3-m profile (Figure 3.77a). These data clearly show that the manure pack was a source of NO_3-N, which leached downward. Core 2, also had elevated NO_3-N concentration in the 0- to 0.6-m layer; whereas, the NO_3-N concentration was less than 8 mg kg^{-1} deeper than 0.6 m. In this regard, Core 2 was similar to Core 3, which was sampled a short distance from the manure pack and corrals. Core 3 contained 6 mg kg^{-1} or less NO_3-N throughout the 3-m profile. The chloride concentration showed a similar distribution among the three cores (Figure 3.77d). Interestingly, above the 1-m depth there was elevated concentration or a bulge of NO_3-N and Cl in the profile. Perhaps in the recent past (i.e., 3 to 5 years) there was a major leaching event and the pulse of NO_3-N and Cl had reached the 1-m depth at the time of sampling. The possibility of contamination of the 0.9- to 1.2-m sample from surface soil during sampling is unlikely since STP concentration did not increase in the same soil layer (Figure 3.77c). Results from Cores 1 and 2 showed the variability under the manure pack. It is possible that Core 2 was collected under a thinner part of the manure pack.

Table 3.48. Soil extractable nitrate nitrogen, ammonium nitrogen, and soil-test phosphorus at the Pasture site and the corral area within Pasture A in fall 2007.

	Nitrate nitrogen			Ammonium nitrogen			Soil-test phosphorus		
	Average	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.
	($mg\ kg^{-1}$)								
Pasture site[z]	4.6	2.2	7.8	6.8	5.0	11	12	3.0	52
Corral area[y]	11	3.2	25	7.0	6.5	7.8	104	42	187

[z] n = 27 samples; 0- to 15-cm soil layer.
[y] n = 3 samples; 0- to 15-cm soil layer.

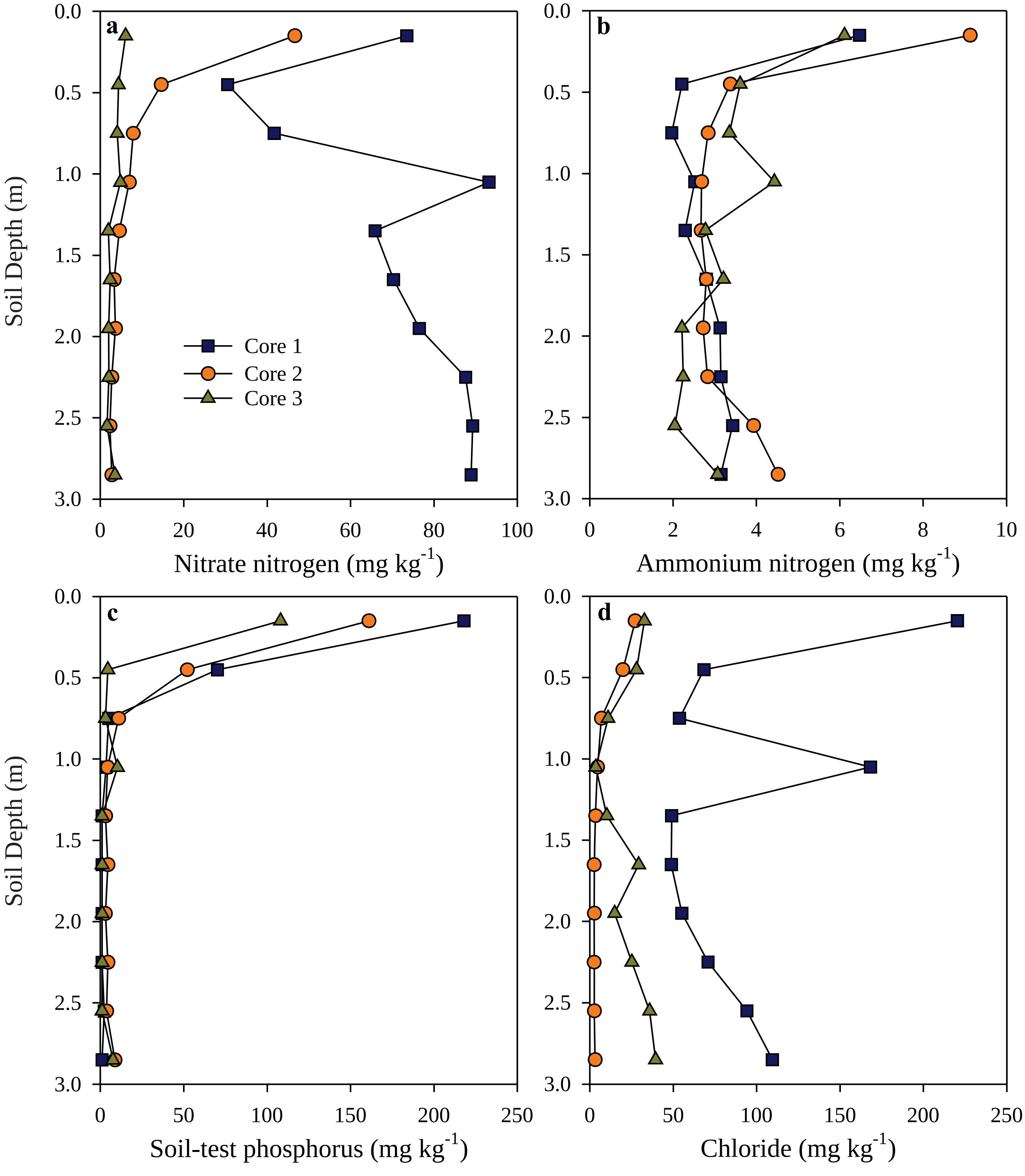

Figure 3.77. Soil extractable (a) nitrate nitrogen (b) ammonium nitrogen, (c) soil-test phosphorus, and (d) chloride at the corral area in Pasture A in October 2009. Cores 1 and 2 were drilled under the manure pack within the corrals and Core 3 was drilled a short distance east of the corrals.

Soil-test P concentration in the 0- to 0.3-m soil layer was higher in Cores 1 and 2 under the manure pack compared to Core 3 (Figure 3.77c). Concentration of STP was also elevated in the 0.3- to 0.6-m layer under the manure pack, suggesting P leaching. Phosphorus is less soluble and mobile than NO_3-N and does not leach as readily. However, accumulated P, from excessive manure application for example, can saturate surface soil with P and some of the P can leach downward (Olson et al. 2010a). The 0- to 0.3-m soil layer in Core 3 had relatively high STP concentration, and this was likely caused by the high density of fecal pats in the area near the corral as described above for the 0- to 15-cm soil samples. However, there was no appreciable P leaching into the 0.3- to 0.6-m layer in Core 3. This suggests that even though STP was high in the top soil layer, P saturation may have been low enough not to cause P leaching compared to the soil under the manure pack.

3.7.3.6 Water Flow and Quality

Edge-of-field stations. The annual flow at Stations 9 and 10 ranged from minimal flow in 2007, 2008, and 2012 to large flows in 2010 and 2011 (Table 3.49). On average, annual flow at Stations 9 and 10 was about 140-fold larger in 2010 and 2011 compared to the other four years. Flow was caused by snowmelt and rainfall runoff with the majority of flow occurred in the spring and early summer (Figure 3.78). At Station 9, snowmelt runoff was dominant in 2009 and 2012 with rainfall runoff dominant in 2008, 2010, and 2011. There was major back up of water from IFC into the flume at Station 9 during the June 17, 2010 flood event. This prevented the collection of flow data, and as a result, the annual flow value for 2010 does not included this event.

The two years with the highest annual flow (2010 and 2011) also had above average precipitation (Sub-section 3.2). Below average precipitation in 2007 and 2012 resulted in much lower amounts of runoff. In contrast, the flow was low in 2008 even though precipitation was well above average.

In the four low-flow years, flow at the downstream station was only 10 to 29% the size of the flow at the upstream station (Table 3.49). This suggests that much of the flow through Station 10 did not reach Station 9 and infiltrated into the soil, and that the drainage area between Stations 9 and 10 contributed little runoff. In the two high-flow years, flow at the downstream station was 3% higher in 2010 and 26% higher in 2011 compared to the upstream station, signifying a net contribution from the corral drainage area between the two stations. The estimated contribution

Table 3.49. Annual flow and the proportions attributed to snowmelt and rainfall runoff at Stations 9 and 10 (corral area) from 2007 to 2012.

	Station 10 (upstream)			Station 9 (downstream)		
Year	Flow (m^3 yr^{-1})	Proportion from snowmelt (%)	Proportion from rainfall (%)	Flow (m^3 yr^{-1})	Proportion from snowmelt (%)	Proportion from rainfall (%)
2007	261[z]	n/a	n/a	75[z]	n/a	n/a
2008	1,071	57	43	180	0	100
2009	2,010	95	5	331	97	3
2010	66,650	<1	100	68,420	<1	100
2011	66,345	8	92	83,797	15	85
2012	106	100	0	11	100	0

[z] Missing snowmelt runoff because flow measurement started in May.

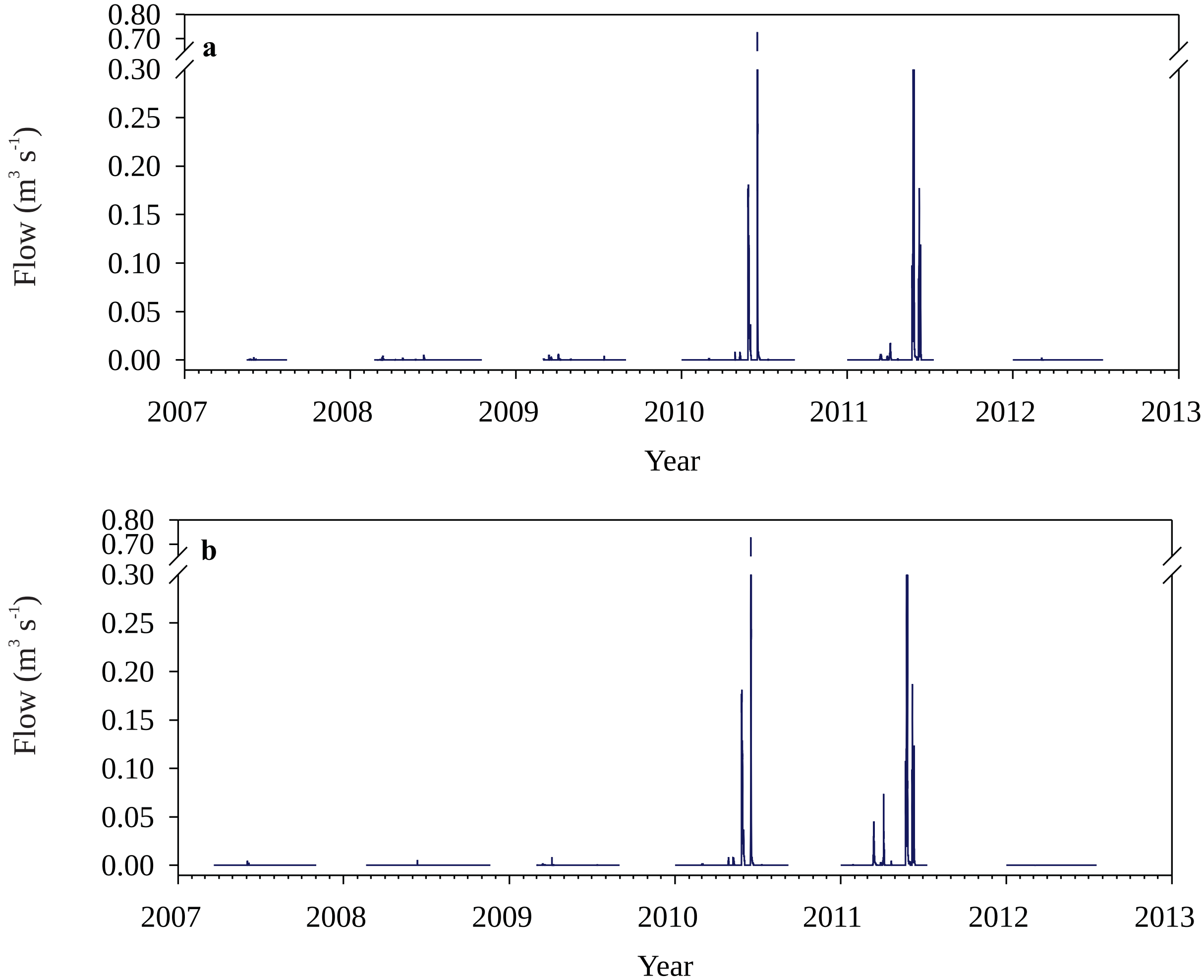

Figure 3.78. Flow data for the edge-of-field (a) upstream (Station 10) and (b) downstream (Station 9) stations at the corral area from 2007 to 2012.

(upstream minus downstream) was 3 and 21% of the total flow at the downstream station in 2010 and 2011, respectively.

Generally, the highest concentrations of TN and TP occurred in the spring (Figure 3.79a,b). Total suspended solids concentration also peaked in the spring. The highest TSS peak occurred at Station 9 in March 2010 (Figure 3.79c). This could be due to a berm that was created when a residential water line was trenched into the soil and crossed the drainage channel between Stations 9 and 10 in September 2009 (Figure 3.80a). The berm was removed and this area was seeded in April 2010 (Figure 3.80b). The majority of the TN was ON (50%) and NO_3-N (33%) and the majority of TP was TDP (86%) at both stations (Tables 3.50 and 3.51).

Concentration of *E. coli* was much higher in the rainfall runoff (May to July) compared to the snowmelt (March to April) runoff (Figure 3.79d), and this seasonality effect on *E. coli* has also been found in other agricultural watersheds in Alberta (Lorenz et al. 2008). Much less biological activity is expected in March and April because of colder temperatures during snowmelt conditions.

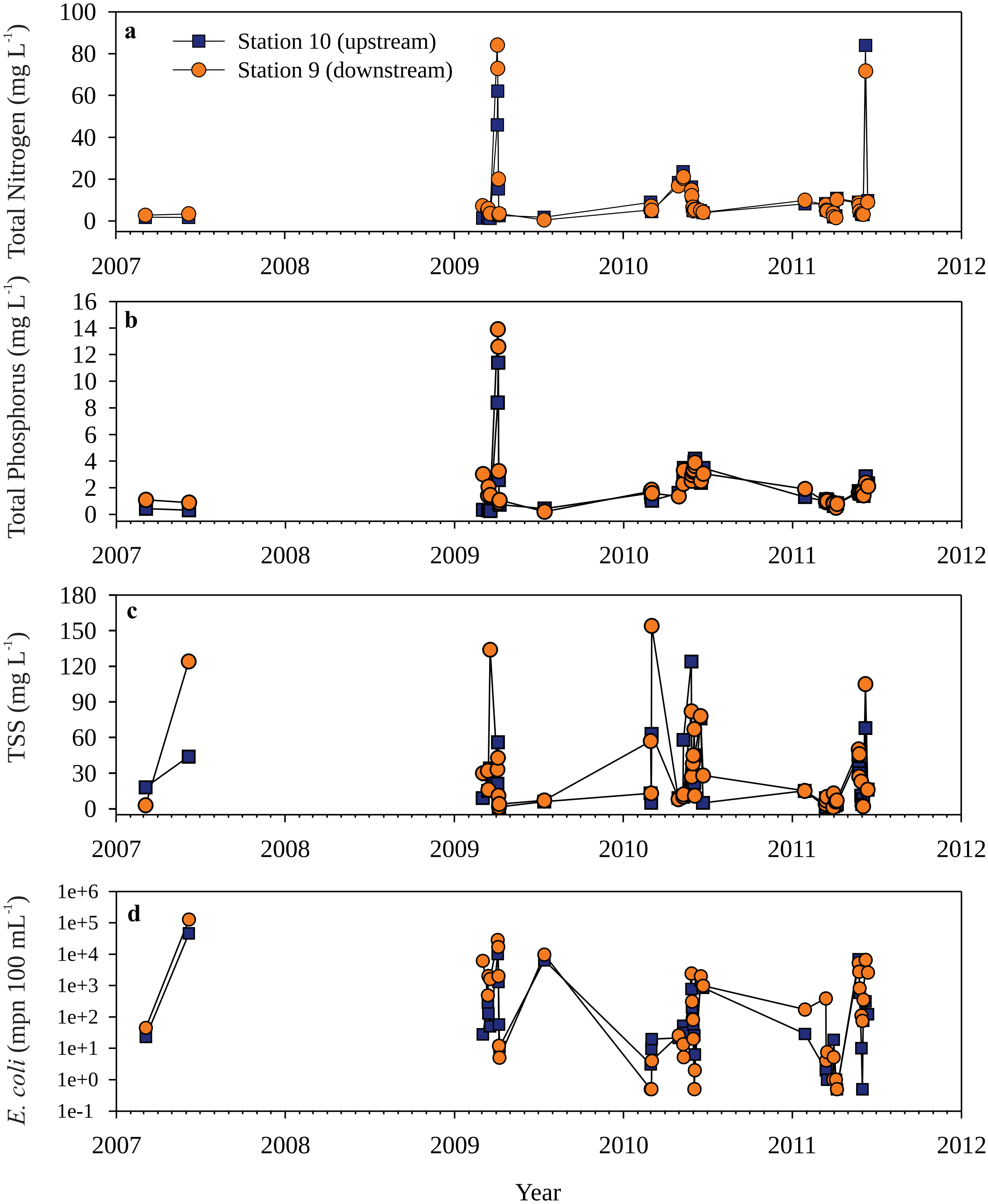

Figure 3.79. Concentrations of (a) total nitrogen, (b) total phosphorus, (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) at the upstream (Station 10) and downstream (Station 9) edge-of-field monitoring stations at the old corral area of the Pasture site from 2007 to 2011 (no samples were collected in 2008 and 2012).

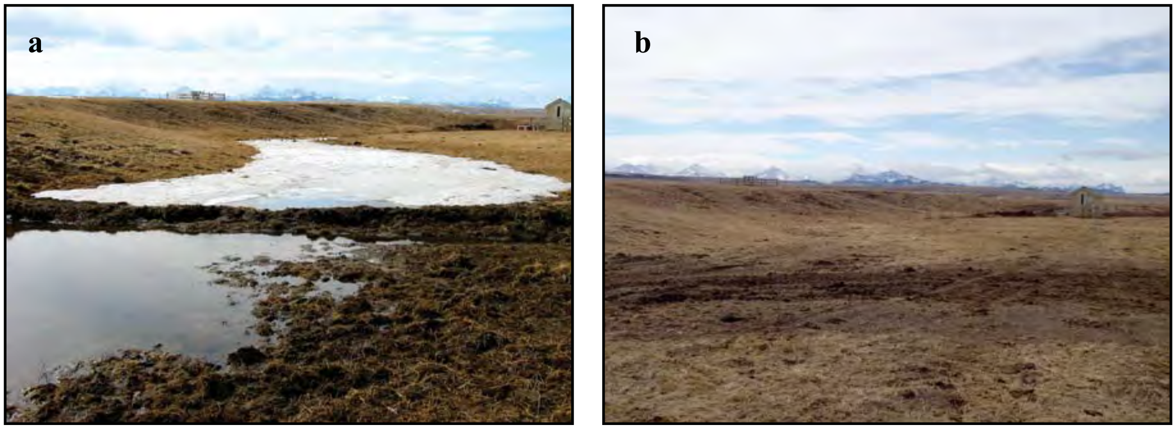

Figure 3.80. The drainage channel between Stations 9 and 10 showing the (a) water line berm on March 8, 2010 and (b) after the berm was removed in April 2010. Station 9 shed is shown on the right-hand side in the images.

Table 3.50. Average nitrogen, chloride, and *Escherichia coli* concentrations for the upstream (Station 10) and downstream (Station 9) stations in the pre- (2007 to 2009) and post-BMP (2010 to 2012) periods, and the average differences between the two stations in the pre- and post-BMP periods.[z]

	TN		ON		NO_3-N		NH_3-N		Cl[y]		*E. coli*	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Station	-----------	(mg L^{-1})	-----------								(mpn 100 mL^{-1})	
					Snowmelt (n=10 pre, 11 post)							
Downstream	20.8	5.67	9.80	2.95	5.05	1.71	4.81	0.94	31.8	12.8	5,725	53
Upstream	13.7	6.02	5.34	3.06	4.04	1.83	3.32	1.05	18.4	14.1	3,188	8
Difference[x]	*7.1a*	*-0.35b*	*4.46a*	*-0.11b*	*1.01a*	*-0.12b*	*1.49a*	*-0.11b*	*13.4a*	*-1.3b*	*2,537*	*45*
					Rainfall (n=2 pre, 18 post)[w]							
Downstream	1.94	12.4	1.60	6.73	0.09	4.91	0.23	0.71	0.49	5.63	68,425	1238
Upstream	1.68	13.5	1.50	7.04	0.07	5.31	0.08	1.09	3.11	5.69	26,200	762
Difference	*0.26*	*-1.10*	*0.10*	*-0.31*	*0.02*	*-0.40*	*0.15*	*-0.38*	*-2.62*	*-0.06*	*42,225*	*476*
					All events (n=12 pre, 29 post)							
Downstream	17.7	9.84	8.44	5.29	4.22	3.69	4.04	0.80	28.7	8.32	16,175	789
Upstream	11.7	10.7	4.70	5.53	3.38	3.99	2.78	1.08	16.8	8.89	7,023	476
Difference	*6.0a*	*-0.86b*	*3.74a*	*-0.24b*	*0.84a*	*-0.30b*	*1.26a*	*-0.28b*	*11.9a*	*-0.57b*	*9,152a*	*313b*

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonium nitrogen, Cl = chloride, *E. coli* = *Escherichia coli*.

[y] Chloride was added as a parameter in October 2008. There were 10 pre-BMP samples (rainfall n=1, snowmelt n=9) collected and analyzed for chloride in 2008 and 2009.

[x] Average differences for pre- and post-BMP periods per parameter and event type followed by letters are significantly different at $P < 0.1$.

[w] Statistical tests not performed because there were only two rainfall runoff samples collected in the pre-BMP period.

Table 3.51. Average phosphorus concentration, total suspended solids concentration, pH, and electrical conductivity for the upstream (Station 10) and downstream (Station 9) stations in the pre - (2007 to 2009) and post-BMP (2010 to 2012) periods, and the average differences between the two stations in the pre - and post-BMP periods.[z]

	TP		TDP		PP		TSS		pH		EC	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Station	($mg\ L^{-1}$)										($\mu S\ cm^{-1}$)	
					Snowmelt (n=10 pre, 11 post)							
Downstream	4.08	1.18	3.43	1.00	0.65	0.18	31	26	7.85	7.66	448	285
Upstream	2.56	1.04	2.12	0.93	0.44	0.11	19	12	7.77	7.66	304	305
Difference[x]	*1.52a*	*0.14b*	*1.31a*	*0.07b*	*0.21*	*0.07*	*12*	*14*	*0.08*	*0*	*144a*	*-20b*
					Rainfall (n=2 pre, 18 post)							
Downstream	0.54	2.42	0.45	2.12	0.09	0.30	66	33	7.71	7.97	144	342
Upstream	0.38	2.59	0.32	2.27	0.06	0.32	25	31	8.16	7.97	292	338
Difference[y]	*0.16*	*-0.17*	*0.13*	*-0.15*	*0.03*	*-0.02*	*41*	*2*	*-0.45*	*0*	*-148*	*4*
					All events (n=12 pre, 29 post)							
Downstream	3.49	1.95	2.93	1.69	0.56	0.26	37	31	7.83	7.85	397	320
Upstream	2.19	2.00	1.82	1.76	0.37	0.24	20	24	7.83	7.85	302	325
Difference	*1.30a*	*-0.05b*	*1.11a*	*-0.07b*	*0.19*	*0.02*	*17*	*7*	*0*	*0*	*95a*	*-5b*

[z] TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TDP = total suspended solids, pH= potential hydrogen, EC = electrical conductivity.
[y] Statistical tests not performed because there were only two rainfall runoff samples collected in the pre -BMP period.
[x] Average differences for pre - and post-BMP periods per parameter and event type followed by lette rs are significantly different at P < 0.1.

Instream stations on IFC. There were no measurable difference in flow between upstream Station 8 and downstream Station 5. Since there were no major tributaries entering IFC between these two stations, the similar flow between the two stations suggests that local surface runoff was small relative to the volume in the creek. The volume measured at Station 9 was less than 0.3% of the volume at Station 5, which is considerably less than the error associated with flow measurement.

The annual flow in IFC at Station 5 varied widely during the 6-yr period with relatively low flows in 2007 and 2012, intermediate flows in 2008 and 2009, and high flows in 2010 and 2011 (Table 3.52). The highest annual flow (2010) was nearly 60 times greater than the lowest annual flow (2007). The majority of flow in most years occurred after the snowmelt period from late May to mid-June. The total volume of water during the post-BMP years (2010 to 2012) was more than seven times greater than the total volume of water during the pre-BMP years (2007 to 2009).

Peak concentrations of TN occurred during rainfall runoff events in May and June in 2010 and 2011 (Figure 3.81a). Total P concentration was generally higher during summer rainfall runoff, except in 2011 when TP concentration was high during spring snowmelt (Figure 3.81b). On average, TN, ON, and P concentrations were higher during rainfall runoff than during snowmelt and base flow (Tables 3.53 and 3.54). Overall, ON was the major form of N and PP was the major form of TP at both stations.

Total suspended solids and *E. coli* concentrations were highest during rainfall runoff events in May and June (Figure 3.81c,d). *Escherichia coli* and TSS concentrations were higher during early summer rainfall runoff than during spring snowmelt and summer base flow at both stations (Tables 3.53 and 3.54). For Alberta, the protection of aquatic life guideline for TSS state that during high flow, a maximum increase of 25 mg L^{-1} from background levels is acceptable at any time when background levels are between 25 and 250 mg L^{-1} (ESRD 2014). If we assume that the base flow TSS concentrations represent background conditions, then the TSS concentrations during rainfall runoff events and overall at both stations were above guidelines (Table 3.54).

The concentration of the N parameters, P parameters, Cl, and *E. coli* at instream Stations 5 and 8 (Tables 3.53 and 3.54) was less than at the edge-of-field Stations 9 and 10 (Tables 3.50 and 3.51). On average, the concentrations of these parameters were 1.5 to 12 times higher at the edge-of field stations compared to the instream stations. In contrast, the average TSS concentration was 6.4 times higher and EC was 1.7 times higher at Stations 5 and 8 compared to Stations 9 and 10. Indianfarm Creek is a highly erosive channel resulting in higher sediment content compared to a smaller grassed drainage channel such as the one between Stations 9 and 10 at the corral area.

Table 3.52. Annual flow and proportions of flow attributed to snowmelt and rainfall (including base flow, dam release, and flood flows included) runoff at Station 5 of the Pasture site from 2007 to 2012.

Year	Flow (m^3 yr^{-1})	Proportion from snowmelt (%)	Proportion from rainfall (%)
2007	416,716	18	82
2008	3,772,959	20	80
2009	1,953,040	63	37
2010	24,407,514	4	96
2011	20,185,407	39	61
2012	505,069	44	56

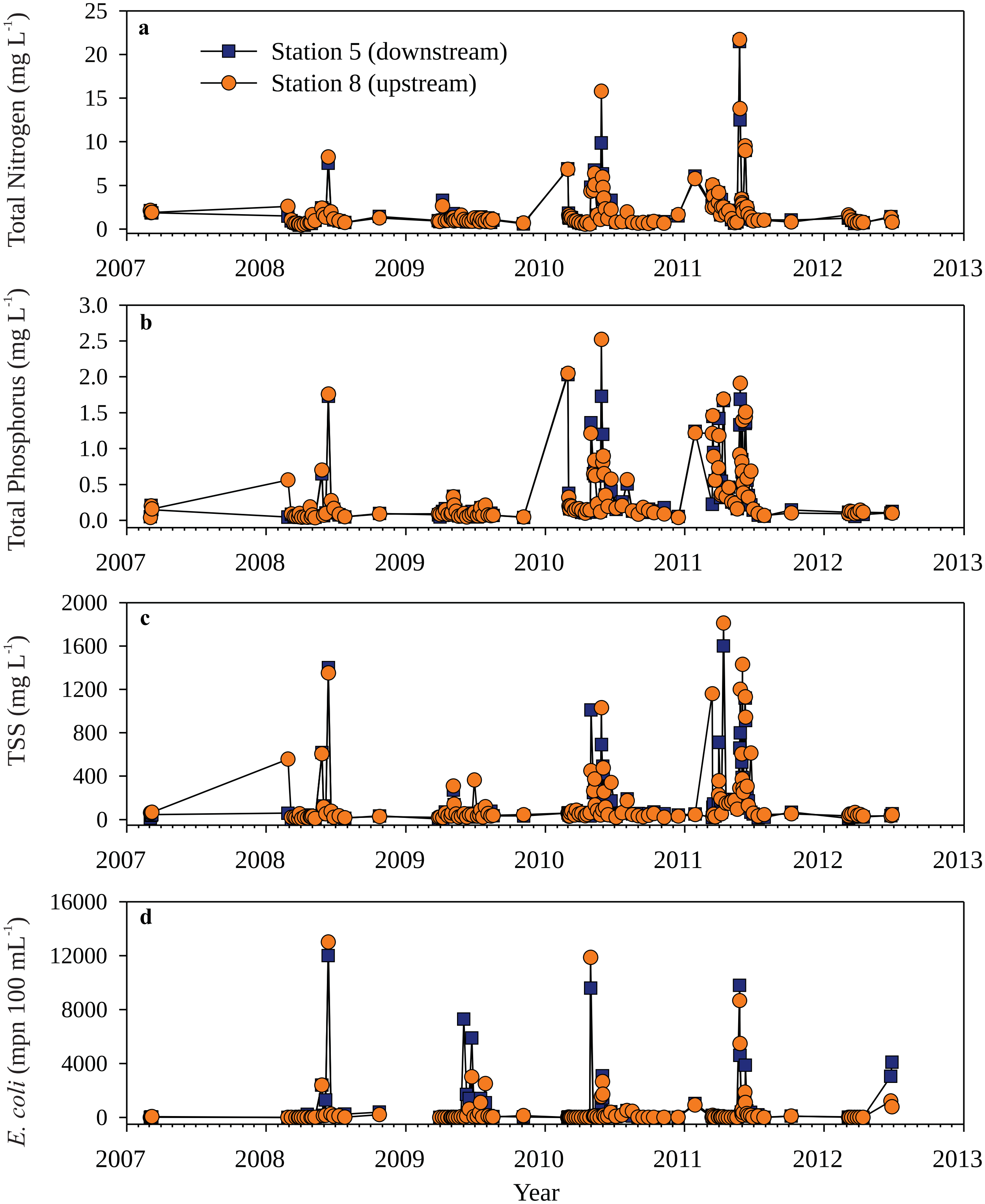

Figure 3.81. Results for (a) total nitrogen, (b) total phosphorus, (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) at the upstream (Station 8) and downstream (Station 5) monitoring stations the Pasture site from 2007 to 2012.

BMP effects on water quality. For all runoff events combined, the concentration of nearly all parameters increased from upstream (Station 10) to downstream (Station 9) edge-of-field sites during the pre-BMP years (2007 to 2009), except for pH (Tables 3.50 and 3.51). The increases ranged from 25% to more than 100%. This supports that the corral area contributed nutrients and bacteria to the drainage channel. This area had a high density of fecal pats because cattle congregated around the corral (Figure 3.67b). In addition, visual observations indicated the pasture was particularly overgrazed in this area. Soil analysis showed that STP in surface soil (0 to 15 cm) was relatively high (104 mg kg^{-1}) at the corral area compared to the rest of the pasture (12 mg kg^{-1}), further suggesting nutrient accumulation in this area of the PST site.

Table 3.53. Average nitrogen, chloride, and *Escherichia coli* concentrations for the upstream (Station 8) and downstream (Station 5) stations in the pre- (2007 to 2009) and post-BMP (2010 to 2012) periods, and the average differences between the two stations in the pre- and post-BMP periods.[z]

	TN		ON		NO_3-N		NH_3-N		Cl^y		*E. coli*	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Station	----------				(mg L^{-1})					----------	(mpn 100 mL^{-1})	
					Snowmelt (n=27 pre[w], 28 post)							
Downstream	1.14	2.21	0.88	1.52	0.15	0.39	0.08	0.28	5.78	9.30	16	60
Upstream	1.14	2.18	0.89	1.52	0.14	0.36	0.09	0.28	5.42	9.35	9	49
Difference	*0*	*0.03*	*-0.01*	*0*	*0.01*	*0.03*	*-0.01*	*0*	*0.36*	*-0.05*	*7*	*11*
					Rainfall (n=9 pre, 32 post)							
Downstream	2.07	4.16	1.84	1.73	0.13	2.15	0.08	0.24	4.91	6.69	2762	1432
Upstream	2.05	4.32	1.82	1.70	0.13	2.33	0.08	0.23	4.59	6.84	2487	1279
Difference[x]	*0.02*	*-0.16*	*0.02*	*0.03*	*0*	*-0.18*	*0*	*0.01*	*0.32*	*-0.15*	*275*	*153*
					Base flow (n=14 pre, 18 post)							
Downstream	1.08	0.89	1.01	0.78	0.03	0.07	0.03	0.03	4.90	7.07	866	63
Upstream	1.14	0.88	1.06	0.76	0.03	0.07	0.03	0.03	4.84	6.54	147	62
Difference	*-0.06b*	*0.01a*	*-0.05b*	*0.02a*	*0*	*0*	*0*	*0*	*0.06*	*0.53*	*719a*	*1b*
					Active runoff - snowmelt plus rainfall (n=36 pre, 60 post)							
Downstream	1.37	3.25	1.12	1.63	0.15	1.33	0.08	0.26	5.47	7.91	789	792
Upstream	1.37	3.33	1.12	1.62	0.14	1.41	0.08	0.25	5.13	8.01	706	705
Difference	*0.01*	*-0.07*	*0*	*0.01*	*0.01*	*-0.08*	*0*	*0*	*0.34*	*-0.10*	*83*	*87*
					All events (n=50 pre[w], 78 post)							
Downstream	1.29	2.71	1.09	1.43	0.11	1.04	0.07	0.21	5.27	7.71	812	624
Upstream	1.30	2.76	1.10	1.42	0.11	1.10	0.07	0.20	5.03	7.67	536	557
Difference	*-0.01*	*-0.05*	*-0.01*	*0.01*	*0*	*-0.06*	*0*	*0.01*	*0.24*	*0.04*	*276*	*67*

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonium nitrogen, Cl = chloride, *E. coli* = *Escherichia coli*.

[y] This water quality parameter was not included until October 2008, so there were 26 pre-BMP samples (6 rainfall, 11 snowmelt, and 9 base flow) collected and analyzed for chloride.

[x] Average differences for pre- and post-BMP periods per parameter and event type followed by letters are significantly different at $P < 0.1$.

[w] n values shown are maximums. The *E. coli* n values for pre-BMP snowmelt and all events was lower because there was missing data on March 28, 2008, April 25, 2008, and March 27, 2009

In contrast, the concentration of many parameters decreased from upstream to downstream at the edge-of-field sites during the post-BMP period for all events (2010 to 2012). The exceptions were *E. coli*, PP, and TSS, which all increased from upstream to downstream in the post-BMP years. However, these increases were less compared to the pre-BMP period (Tables 3.50 and 3.51). This suggests that removing the corrals to discourage cattle from gathering in this area had a positive effect on water quality. Also, the rotational grazing plan reduced the time cattle were in Pasture A, which included the corral area, by 70%, and this may have had a positive effect. The upstream-downstream differences between the pre- and post-BMP periods for all events were significantly different for all N parameters, TP, TDP, Cl, *E. coli*, and EC (Tables 3.50 and 3.51). The upstream-downstream differences for PP and TSS were also less for the post-BMP period, but not significantly different from the pre-BMP years.

Table 3.54. Average phosphorus concentration, total suspended solids concentration, pH, and electrical conductivity for the upstream (Station 8) and downstream (Station 5) stations in the pre- (2007 to 2009) and post-BMP (2010 to 2012) periods, and the average differences between the two stations in the pre- and post-BMP periods.[z]

	TP		TDP		PP		TSS		pH		EC	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Station	----------	----------	----------	----------	(mg L^{-1})	----------	----------	----------			($\mu S\ cm^{-1}$)	
					Snowmelt (n=27 pre, 28 post)							
Downstream	0.09	0.50	0.03	0.27	0.07	0.23	39	143	8.35	8.12	607	545
Upstream	0.12	0.53	0.03	0.27	0.09	0.26	67	182	8.31	8.13	614	549
Difference	*-0.03*	*-0.03*	*0*	*0*	*-0.02*	*-0.03*	*-28*	*-39*	*0.04a*	*-0.01b*	*-7*	*-4*
					Rainfall (n=9 pre, 32 post)							
Downstream	0.34	0.65	0.05	0.25	0.29	0.40	275	333	8.30	8.28	497	506
Upstream	0.36	0.68	0.05	0.26	0.30	0.42	271	357	8.30	8.27	487	511
Difference[y]	*-0.02*	*-0.03*	*0*	*-0.01*	*-0.01*	*-0.02*	*4*	*-24*	*0*	*0.01*	*10*	*-5*
					Base flow (n=14 pre, 18 post)							
Downstream	0.09	0.12	0.03	0.02	0.07	0.11	39	46	8.44	8.35	511	632
Upstream	0.10	0.15	0.02	0.02	0.08	0.13	61	73	8.47	8.38	507	628
Difference	*-0.01*	*-0.03*	*0.01*	*0*	*-0.01*	*-0.02*	*-22*	*-27*	*-0.03*	*-0.03*	*4*	*4*
					Active runoff - snowmelt plus rainfall (n=36 pre, 60 post)							
Downstream	0.16	0.58	0.03	0.26	0.12	0.32	98	244	8.34	8.21	579	524
Upstream	0.18	0.61	0.03	0.26	0.15	0.35	118	275	8.31	8.21	582	529
Difference	*-0.02*	*-0.03*	*0*	*0*	*-0.02*	*-0.03*	*-20*	*-31*	*0.03*	*0*	*-3*	*-5*
					All events (n=50 pre, 78 post)							
Downstream	0.14	0.48	0.03	0.20	0.11	0.27	82	198	8.37	8.24	560	549
Upstream	0.16	0.50	0.03	0.21	0.13	0.30	102	229	8.36	8.25	561	552
Difference	*-0.02*	*-0.02*	*0*	*-0.01*	*-0.02*	*-0.03*	*-20*	*-31*	*0.01a*	*-0.01b*	*-1*	*-3*

[z] TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, pH= potential hydrogen, EC = electrical conductivity.
[y] Average differences for pre- and post-BMP periods per parameter and event type followed by letters are significantly different at $P < 0.1$.

For most water quality parameters, the concentrations were similar between the upstream Station 8 and downstream Station 5 on IFC for all events combined (Tables 3.53 and 3.54). This was true for the pre-BMP and post-BMP periods and for the rainfall, snowmelt, active runoff (snowmelt plus rainfall), and base-flow events. The downstream-upstream differences of parameter concentrations between the pre- and post-BMP periods were not significantly different for active runoff and all events combined. This suggests that the BMPs had no measureable effect on the mainstem water quality between Stations 8 and 5 at the PST site.

Though not significantly different between the pre- and post-BMP periods for all events combined, *E. coli* concentration increased by 51% from upstream to downstream during the pre-BMP years; whereas, the increase was only 12% during the post-BMP period (Table 3.53). Further to this, the contribution of *E. coli* was significantly less within the reach from Station 8 to Station 5 in the post-BMP period compared to the pre-BMP period for base flow. During the pre-BMP period, base flow *E. coli* concentration increased nearly six-fold from upstream to downstream; whereas, the concentration was nearly the same between the two stations during the post-BMP period. This suggests that the removal of the corrals and implementing rotational grazing may have reduced *E. coli* concentration. Cattle spent about 70% less time in Pasture A during the post-BMP period. Plus, it was observed that, when in Pasture A, cattle preferred to drink from the off-stream water source, and this would have reduced the time cattle were in the riparian area along the creek.

Although many parameters changed little between the two instream monitoring stations, TSS concentration decreased during base flow from upstream to downstream by 36% in the pre-BMP period and by 37% in the post-BMP period (Table 3.54). Similar decreases were also observed during snowmelt. Several beaver dams were observed in the reach between Stations 5 and 8 (Figure 3.82) during the post-BMP period, and these dams created small pools of water. Sediment likely settled in these ponds during low flow.

Figure 3.82. Beaver dam downstream of Station 5 on July 29, 2010.

The downstream-upstream differences in TN and ON concentrations between the pre- and post-BMP periods were significantly different for base flow (Table 3.53). However, instead of an improvement, the contribution of these two parameters increased in the post-BMP period compared to the pre-BMP period. Regardless, the change in TN and ON concentrations was small for both periods. Total N and ON concentration decreased by 5% from the upstream station to the downstream station during the pre-BMP period, and the concentrations increased by 1 to 3% from upstream to downstream during the post-BMP period. It is unknown what may have caused this difference between the two periods, but it is likely not related to the BMPs.

As with the edge-of-field stations, the flow at Stations 5 and 8 was much larger during the post-BMP period compared to the pre-BMP period, with the former more than seven-fold greater than the latter (Table 3.52). The concentrations for nearly all parameters increased ranging from 1.3 to 10 fold in the post-BMP period compared to the pre-BMP period for all events combined (Tables 3.53 and 3.54). The notable exception was *E. coli* concentration, which was less in the post-BMP period at Station 5 (downstream), compared to pre-BMP period, and was similar between the pre- and post-BMP periods at Station 8 (upstream). Again, this may suggest a positive effect by the BMPs on *E. coli* concentration; however, the difference between the pre- and post-BMP periods was not significant.

The above results show a scale difference between the edge-of-field corral area (Station 9 and 10) and the monitored reach on IFC (Stations 5 and 8) in terms of changes to water quality from upstream to downstream and the response to BMPs. The total 6-yr volume of water through Station 9 was less than 0.3% of the total volume of water that flowed by Station 5. Differences in water quality parameter concentrations were observed between the edge-of-field stations. The concentration of most parameters was similar between the two stations on IFC. The corral area showed a positive response to the BMPs; whereas, this was generally not the case for the IFC mainstem between Stations 5 and 8, expect possibly for *E. coli*. The contributions from non-point sources along the relatively short reach (about 1 km) between Stations 5 and 8 were small compared to the volume of water in IFC. The water flow and quality at the upstream Station 8 represented about 68% (9580 ha) of the drainage area of the whole watershed; whereas, the additional contributing area between Stations 8 and 5 was only about 19 ha, which represented 0.2% of the drainage area to Station 5.

3.7.4 Conclusions

- The rotational grazing plan, off-stream watering, and windbreaks successfully reduced the time cattle spent in the riparian pasture up to 70%. When the cattle were in the riparian pastures, they tended to drink from the off-stream watering system. The producer was satisfied with the implementation, management requirements, and performance of the BMP.

- The BMP cost $16,643 and required 148 h to implement. All of the costs were during the implementation of the BMPs, and most of the cost (85%) was for the off-stream watering system.

- Based on the Cows and Fish assessment, riparian quality improved at the PST site. The overall riparian function rating increased from unhealthy in 2007 to healthy with problems in 2012, suggesting a positive effect of the BMPs. Improvement was observed for the vegetation and soil/hydrology factors.

- Species richness and diversity increased from 2008 to 2012 in all vegetation zones; however, these increases were mostly due to invader species such as smooth brome and Kentucky bluegrass. There were increases in desirable shrub species, such as prickly wild rose and western snowberry in all three zones and balsam poplar was also found on two transects in the post-BMP period. There was a decrease in willow species cover in the riparian zone and this may have been due to localized stream bank erosion caused by extremely high flows in 2010 and 2011.

- Rangeland health rating was higher in the post-BMP period compared to the pre-BMP period. Rangeland health rating increased with time, but remained in the healthy with problems category. Average percent grass and litter cover increased from the pre-BMP period to the post-BMP period. The increase in foothills rough fescue in the post-BMP period may indicate that the reduced grazing pressure will promote recovery of some natural plant vigor in the pasture.

- The bioengineering techniques used on a highly eroded reach of IFC were expensive and labour intensive. Because high flows in the creek occurred shortly after the bioengineering structures were installed, nearly all of the structures were either badly damaged or washed away twice. Techniques such as live staking on less risky, smaller scale project may have more success.

- Pastures are subject to STP accumulation when cattle congregate in a particular area for extended periods. The corral area had an STP concentration of 104 mg kg^{-1}, which was about nine-fold higher compared to the rest of the PST site.

- The removal of the corrals and rotational grazing significantly improved water quality in the post-BMP period compared to the pre-BMP period at the edge-of-field site.

- At the larger scale on IFC, the BMPs had no effect on improving water quality. There was some tendency for less TN, ON, TSS, and *E. coli* in the post-BMP period; however, the differences between the two BMP periods were not significant.

- The concentration of water quality parameters were higher at the smaller scale of the edge-of-field sites compared to the mainstem of IFC. It may be easier to measure a positive response to BMPs at a smaller scale.

- The results support the hypothesis that the implemented BMPs of removing the corral from a drainage area and using a rotational grazing plan to reduce the time cattle spent in the riparian pasture would improve water quality. However, this was generally only measurable at the smaller edge-of-field scale and was not measureable on the mainstem of IFC. The dissolved forms of nutrients were affected more by the BMPs than the particulate forms at the edge-of-field site. The results also support the hypothesis that the rotational grazing improved riparian and rangeland health.

3.8 Wintering Site

3.8.1 Introduction and Hypotheses

The WIN site was similar to, and immediately upstream from, the PST site. The farm unit included pastures along IFC as well as nearby cropland. The pastures were used for grazing, and when in the pastures, cattle had unrestricted access to the creek as a source of water. In addition to the natural erosion processes in IFC, cattle access had degraded the riparian zone and accelerated stream-bank erosion.

The BMPs at this site focused on the control of cattle access to the creek and riparian area. They included wintering site relocation, rotational grazing, off-stream watering, and portable windbreaks. Water quality was monitored on the mainstem of IFC, at stations upstream and downstream of the WIN site. The post-BMP period began when the rotational grazing plan was initiated in January 2009. Bioengineering techniques were also demonstrated at two eroded riparian areas at the WIN site; however, bioengineering was not considered part of the BMP plan.

The assumptions underlying the chosen BMPs were that the winter bedding and feeding site adjacent to the creek, and the direct access by cattle to the creek, contributed nutrients and bacteria to the water through runoff processes, and/or direct input. The source of these nutrients could include sediment loss during rainfall and snowmelt runoff events, and this loss can be enhanced by riparian degradation. Fecal pats in the riparian area could also be a source of nutrients and bacteria during runoff events, and direct input could occur when cattle enter the creek. The hypotheses were:

- The relocation of the winter bedding and feeding site away from the creek and the use of rotational grazing to keep cattle out of the riparian area during the more sensitive time of the grazing season would improve riparian quality along IFC, and in turn, reduce the concentration of nutrients (N and P), sediment, and bacteria in the creek.
    - Particulate nutrients were expected to be reduced more than dissolved nutrients because of improved bank stability and riparian quality. Bacteria would be reduced by minimizing the deposition of fecal pats in the riparian area along the creek.

3.8.2 Methods

3.8.2.1 Site Description and Management

The WIN site was in the northern part of watershed, adjacent to IFC (Figure 3.83), and immediately upstream of the PST site (Figure 3.4). It was part of a larger management unit, which included three quarter sections of land (Figure 3.83), but the WIN site itself was about 5 ha in size along the reach between the two water monitoring stations. The land was primarily used for grain crops, hay production, and cattle grazing. All of the pasture area was either adjacent to IFC or one of its tributaries.

The areas adjacent to IFC and the tributary at the WIN site was within the ZUN1/SC1l soil landscape model, as described in AGRASID (Alberta Soil Information Centre 2013). The soil in the model is an Orthic Regosol and includes miscellaneous undifferentiated material, with well drained characteristics. The landform in the model is described as a low relief valley with a floodplain, and slopes ranging from 1 to 5% on the floodplain, and up to 15% on the side slopes. The parent material is described as undifferentiated material. The surface soil had a clay texture (26.3% sand, 40.5% clay), a pH of 6.7, electrical conductivity of 1.5 dS m^{-1}, 7400 mg kg^{-1} TN, 1163 mg kg^{-1} TP, and 17.3% organic matter (Appendix 4).

The middle quarter section and a portion of the east quarter section were within the CWY1/U1l soil landscape model (Alberta Soil Information Centre 2013). The soils in this model are Orthic and Rego Black Chernozems, and include dominant (60% or more) Cowley soil series and a significant (10 to 30%) Cowley-ZT soil series, with well drained characteristics. The landform in the model is described as undulating, with low relief and a limiting slope of 2%, and parent material consists of medium textured water-laid sediments.

Most of the west quarter section was within the CWY6/U1l soil landscape model (Alberta Soil Information Centre 2013). The soils in this model are Orthic and Rego Black Chernozems, and includes dominant (60% or more) Cowley soil series with a significant (10 to 30%) Oldman soil series, with well drained characteristics. The landform in the model is described as undulating, with low relief and a limiting slope of 2%, and parent material consists of fine and medium textured water-laid sediments.

Prior to the implementation of the BMP plan, cattle had full access to the creek during spring runoff and spring rain events (Table 3.55). Direct cattle access to the creek was evident by the amount of erosion along the stream banks and within the riparian area. A winter bedding and

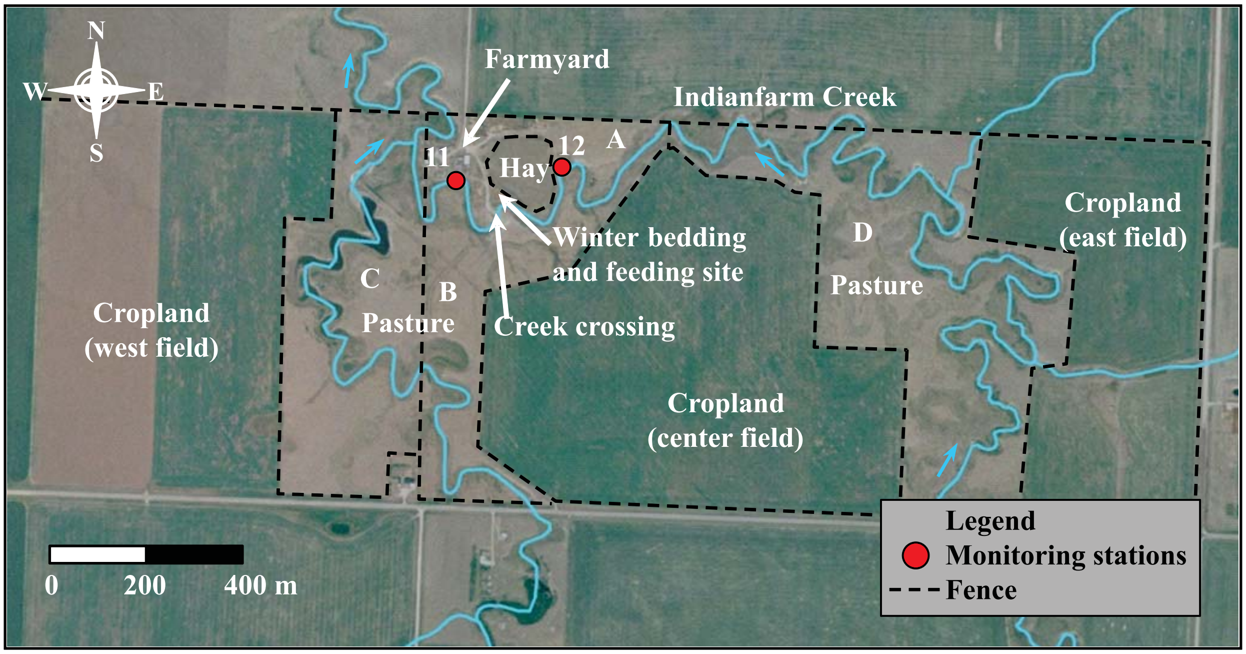

Figure 3.83. The Wintering site and associated farm management unit.

feeding site was in the floodplain just south of the farmyard buildings (Figure 3.83) and about 15 m from the edge of IFC (Figure 3.84). Due to the proximity to the water, the cattle frequently drank from the creek. There was a nearby cattle and vehicle crossing (compacted soil bridge) in the creek, and this allowed the cattle to access the pasture and cropland to the south of the creek.

Livestock management at the WIN site in 2007 and 2008 was similar to practices in previous years. The herd size was fairly constant with time. In 2008, about 35 cows were wintered from December through April near IFC just south of the farm buildings (Figure 3.83; Table 3.55). The cattle calved in late February to mid-March and remained near the corrals and WIN site until mid to late May. On June 1, the cow-calf pairs were moved to the quarter section west of the farmyard and away from the creek. In July, the cattle were allowed access to the creek near the WIN site and to the east of the farmyard. The cattle had access to the creek until late-August. Following harvest, the cow-calf pairs were allowed to graze the stubble field southeast of the WIN site; however, they continued to access the creek for water and shelter until winter feeding began in November.

Table 3.55. Cattle management and grazing at the Wintering site in 2008.

Season	Dates in grazing area	Grazing area[z]	Livestock[y]	Days in grazing area
2007-08 winter	December to January	B	35 c	62
2008 winter	February to mid-March	A[x]	35 cc	30
2008 spring	Late-March to mid-late May	A and B	35 cc	60
2008 spring	June 1 to July	C	35 cc	30
2008 summer	July to late August	D	35 cc	54
2008 summer/fall	Late August to November	B & crop stubble	35 cc	unknown
2008 fall/winter	November to December	A	35 c	unknown

[z] A, B, C, and D refer to pasture areas (Figure 3.83).
[y] c = cows; cc = cow-calf pairs.
[x] Calving by corrals and barn in the farmyard.

Figure 3.84. The wintering bedding and feeding site adjacent to Indianfarm Creek during spring 2008 prior to the implementation of the beneficial management practices plan.

The cropland (Figure 3.83) was generally seeded to annual crops, usually barley, in April or May, and harvested in late August or in September. Nitrogen fertilizer was usually banded in the spring prior to seeding. Phosphorus fertilizer, when used, was applied with the seed. Other crops were also produced. For example, in 2011, the east field was seeded to barely and under seeded to alfalfa (*Medicago sativa* L.), smooth bromegrass (*Bromus inermis* Leyss), and crested wheatgrass (*Agropyron cristatum* L.).

3.8.2.2 Implementation of Beneficial Management Practices

The post-BMP period began in 2009 after 2 yr of the pre-BMP monitoring period. The BMP plan consisted of two main parts: (1) re-location of the wintering bedding and feeding site away from the creek and (2) rotational grazing of the cattle among several pastures including a riparian pasture. These BMPs were supported by the installation of off-stream watering systems to provide water and a portable windbreak (2.6 m high by 9.3 m long) to provide shelter. In addition, demonstration sites of bioengineering techniques were established along IFC.

Most of the infrastructure for the BMPs was installed in fall 2008. The new winter bedding and feeding site was located further away from the creek (70 m) on relatively level ground and about 95 m east of the farmyard corrals and bale storage area (Figure 3.85). The windbreak for the site was constructed with large wooden posts, cross boards, and vertical planks (Figure 3.86). Though the new site was located further away, it was still relatively close to IFC. A barbwire fence was constructed south and east of the windbreak to prevent cattle from accessing the creek. This area, along with the windbreak, was referred to as Pasture A (Figure 3.85). When at the new bedding and feeding site in Pasture A, cattle had access to a small grazing area excluded from IFC. Water for this pasture was provided by a new, permanent, year-round water system installed a few metres west of the windbreak. The new water system included a 3.18-cm poly pipe trenched 2.5 m into the ground from a water supply at a nearby barn, a 3-m^2 concrete pad, and a 300-watt Edwards Energy Efficient water trough with a capacity for 50 to 75 cow-calf pairs. Even though the new winter bedding and feeding site was still relatively close to IFC, the local topography limited runoff from reaching IFC. No runoff was observed entering IFC from the new site during the post-BMP period.

In addition to relocating the bedding and feeding site, a detailed rotational grazing plan was developed. As part of the rotational grazing plan, a riparian pasture (i.e., Pasture E) was created by crossing fencing Pasture B with a barbwire fence (Figure 3.85). Off-stream water was supplied to Pasture B using a Kellen Solar Water System (Lumsden, Saskatchewan) and consisted of a 1900-L plastic trough, 64-watt solar panel, battery, and control panel. The water system was installed in spring 2009 and water was obtained from an existing well on the south site of IFC and about 50 m north of the trough.

The BMP rotational grazing plan involved moving the cattle among the five pastures (A, B, C, D, and E; Figure 3.85) and the three crop fields (west, center, and east; Figure 3.83). The crop fields were used for fall grazing after harvest. Typically each year, the cattle were kept in Pasture A (i.e., the new wintering bedding and feeding site) and farmyard corrals from January to mid-spring (Tables 3.56 and 3.57). Calving occurred for about 2 wk each February. Then from mid-spring to early summer, Pastures B, C, and D were mainly used. The key strategy of the BMP grazing plan,

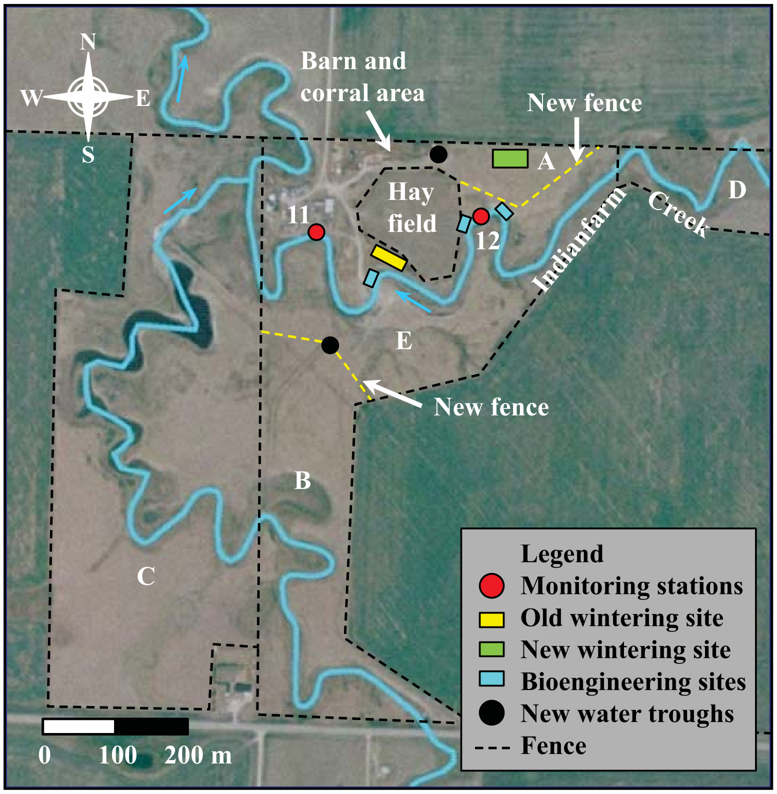

Figure 3.85. Infrastructure installed in 2008 for the beneficial management practices plan at the Wintering site.

Figure 3.86. The wintering bedding and feeding site constructed in 2008.

which differed from previous management, was not to use the riparian pasture (i.e., Pasture E) during spring when riparian areas are most vulnerable to degradation and spring runoff. Cattle were allowed to access Pasture E starting in mid to late July for about 2 to 3 wk. Then from late July or early August, the cattle mainly grazed Pastures B, C, and D until into September. In 2010 and 2012, Pasture E was used for a few days (3 to 6 d) during this late summer period. Then from September to late fall, the crop fields were used for fall grazing in addition to Pastures B, C, and D. In October, the calves were weaned and later sold. From late fall to early winter, the cattle generally had access to Pastures A, B, E, and the Center Field, and the cattle were fed hay bales. More specific details are shown in Tables 3.56 and 3.57.

Table 3.56. Rotation grazing schedule of cattle at the Wintering site during part of the post-BMP period in 2009 to 2010.

Dates on site	Livestock[z]	Area grazed	Days on site
		2009	
Jan 1 to May 10	35 c[y]	Pasture A	130
May 11 to Jun 5	35 cc	Pasture B	25
Jun 6 to Jul 10	35 cc	Pasture C	35
July 11 to Jul 24	35 cc	Pastures E	14
July 25 to Aug 20	35 cc	Pasture D	27
Aug 21 to 27	35 cc	Pasture E	7
Aug 26 to Sep 29	35 cc	Pasture D and East field	34
Sep 30 to Nov 1	35 cc	Pasture E and Center field	33
Nov 2 to Dec 31	35 c	Pasture C, B, and Center field	60
		2010	
Jan 1 to May 14	36 c[y]	Pasture A and Hay field	134
May 15 to 24	36 cc	Pasture B	10
May 25 to Jun 12	36 cc	Pasture C	19
Jun 13 to Jul 26	36 cc	Pasture D	44
Jul 27 to Aug 9	36 cc	Pasture E	14
Aug 10 to 14	36 cc	Pasture B	5
Aug 15 to Sep 17	36 cc	Pasture C	34
Sep 18 to 23	36 cc	Pasture E	6
Sep 24 to Sep 30	36 cc	Pasture C	7
Oct 1 to 19	36 cc	Pasture D and East field	19
Oct 20 to 24	36 cc	Pasture A	5
Oct 25	26 c	Pasture E	1
Oct 26 to Nov 15	26 c	Pasture C and West field	21
Nov 16 to 29	26 c	Pastures A, E[x], and Center field	14
Nov 30 to Dec 20	30 c	Pastures A, E[x], and Center field	21
Dec 21 to 31	42 c + 1 b	Pastures A, E[x,w], and Center field	11

[z] cc = cow-calf pairs, c = cows, b = bull.
[y] Calving occurred during February and lasted two weeks.
[x] Cattle were feed barley and hay (brome/alfalfa/prairie grass mix).
[w] On December 21, 12 cows and one bull added to Pastures A and E and Centre field.

Table 3.57. Rotation grazing schedule of cattle at the Wintering site during part of the post-BMP period in 2011 to 2012.

Dates on site	Livestock[z]	Area grazed	Days on site
		2011	
Jan 1 to Feb 15	42 c + 1 b	Pasture A, E, and Center field	46
Feb 16 to 20	38 c	Pasture A	5
Feb 21 to Mar 29	38 c	Farmyard corrals	37
Mar 30 to May 19	35 cc	Pasture A	51
May 20 to 28	38 cc + 1 b	Pasture B	9
May 29 to Jun 13	38 cc + 1 b	Pasture C	16
May 29 to Jun 13	1 cc + 1 c + 1 b	Pasture A	16
Jun 14 to Jul 12	37 cc + 1 c + 1 b	Pasture D	29
Jul 13 to Aug 2	37 cc + 1 c + 1 b	Pasture E	21
Aug 3 to 18	37 cc + 1 c	Pasture C	16
Aug 19 to Sep 1	37 cc + 1c	Pasture B	14
Sep 2 to 10	37 cc + 1 c	Pasture D	9
Sep 11 to 24	37 cc + 1 c	Pasture D and East field	14
Sep 25 to Oct 9	37 cc + 1 c	Pasture D and Center field	15
Oct 10 to 18	37 cc + 1 c	Pastures C, B, and West field	9
Oct 19	37 cc + 1 c	Farmyard corrals (weaning)	1
Oct 20 to 21	38 c + 2 cc	Pasture A	2
Oct 22 to Dec 31[y]	41 c	Pastures A, B, E, and Center field	71
		2012	
Jan 1 to Feb 15	41 c	Pasture A, E, and Center field	46
Feb 16 to 20	38 c	Pasture A	5
Feb 21 to Apr 14	38 cc	Farmyard corrals	54
Apr 15 to May 14	36 cc[x]	Pasture A and Farmyard corrals	30
May 15 to 28	36 cc + 1 b	Pasture B	14
May 29 to Jun 15	34 cc + 1 c + 1 b	Pasture C	18
June 16 to Jul 8	34 cc + 1 c + 1 b	Pasture D	23
July 9 to Aug 1[w]	34 cc + 1 c + 1 b	Pasture E	24
Aug 2 to 6	34 cc + 1 c + 1 b	Pasture C	5
Aug 7 to 19	34 cc + 1 c + 1 b	Pastures B and C	13
Aug 20 to 22[v]	34 cc + 1 c	Pastures B, C, and E	3
Aug 23 to Sep 1	34 cc + 1 c	Pasture D	10
Sept 2 to 29	34 cc + 1 c	Pasture D and East field	28
Sept 30	34 cc + 1 c	Pasture D and Center field	1
Oct 1 to 15	34 cc + 1 c	Pasture C and West field	15
Oct 16 to 19[u]	34 cc + 1 c	Pasture A and Farmyard corrals	4
Oct 20 to Dec 31	34 cc + 1 c +1 b	Pastures A, E, and Center field	73

[z] cc = cow-calf pairs, c = cows, b = bull.
[y] Starting November 9, the cattle were fed alfalfa-brome bales.
[x] Not all cows had calves.
[w] July 30: 1 cow-calf pair +1 cow + 1 heifer in Pasture A.
[v] Aug 20: the bull was moved to Pasture A.
[u] Starting October, the cattle were fed alfalfa-brome bales and barley green-feed bales.

3.8.2.3 Bioengineering

Three bioengineering sites were constructed along the stretch of IFC that flowed through the WIN site (Figure 3.85). Site 1 was established in spring 2009 immediately downstream from the creek crossing (Figure 3.87a). Approximately 160 sand-bar willow and 40 cottonwood (unknown native species) were planted as live stakes on May 21, 2009. The willows were collected along reaches of IFC in April 2009. The willows were in a dormant stage and they were kept submerged in water under cool conditions until planting. A rebar was used to punch 0.5-m holes in the ground and the live-stakes were inserted into the holes. The live stakes were placed about 1 m apart and within 2 m of the edge of IFC. The entire area planted was about 10 m long on both sides of the creek. An electric fence was installed around the planted area to prevent damage from livestock (Figure 3.87b). Survival counts of the live stakes were completed annually at the end of each summer.

The two additional bioengineering sites were constructed in April 2010. Site 2 was located upstream of water monitoring Station 12 and Site 3 was located downstream of Station 12 (Figure 3.85). A contractor was hired to construct both sites when the water level in the creek was the lowest. The contractor used conventional and unconventional bioengineering methods as described for the PST site (Sub-section 3.7.2.6). Four species of cuttings were used at both sites: sandbar willow, red osier dogwood, balsam poplar, and prickly wild rose. The cuttings were collected from in the Oldman Watershed Basin and the local IFC watershed.

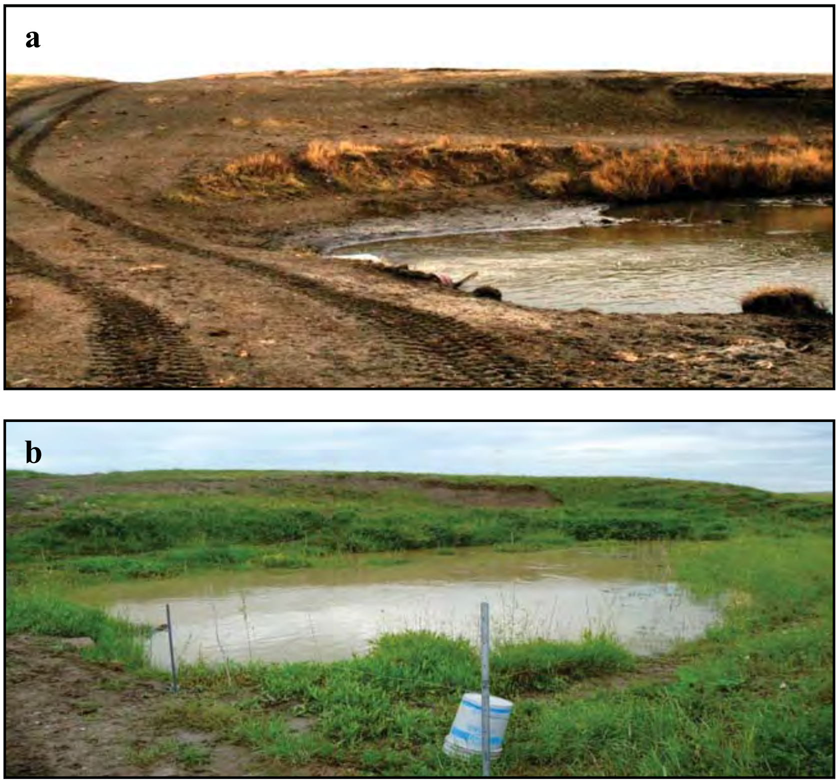

Figure 3.87. Bioengineering Site 1 (a) before and (b) after planting of the live stakes and installation of the electric fence in spring 2009.

At Site 2, one wattle fence was installed at low water level constructed with wood boards (Figure 3.88a). Live stakes were planted in front of and behind the fence. Four rows of sediment stops were installed above the wattle fence. The sediment stops were used to slow the movement of soil downslope to aide in the establishment of juvenile rose shrubs that were trying to grow on the slope. In the center of the slope, a modified brush layer was installed. It was placed strategically on the slope based on evidence of hydrological activity, where runoff seemed to flow the most down the slope. The brush layer had live cuttings, unlike at the PST site where only wood boards were used.

At Site 3, conventional bioengineering techniques were used. A wattle fence constructed from live materials was placed at low water level (Figure 3.88b). Cottonwood stakes were used as fence posts to hold willows used as the horizontal fence component. Red osier dogwood and prickly wild rose were also planted vertically into the fence for extra support and shrub growth. Live stakes were planted in front of and behind the wattle fence after soil was back-filled into the fence. Jute fabric was laid on top of the wattle fence to slow the movement of water and soil through the fence. A sediment stop was installed further up slope and slightly up-stream, also to slow erosion of the slope.

A native reclamation grass seed mixture was dispersed on Sites 2 and 3. Beaver fences (steel posts and wire mesh) were installed along the creek edge directly in front of bioengineering structures. As well, temporary electric fences were installed by the landowner around the sites to protect from livestock damage when Pasture E was grazed.

A survival count was recorded at the end of the summer to determine how many willows survived. Photo points were also established to visually record the growth at the two sites.

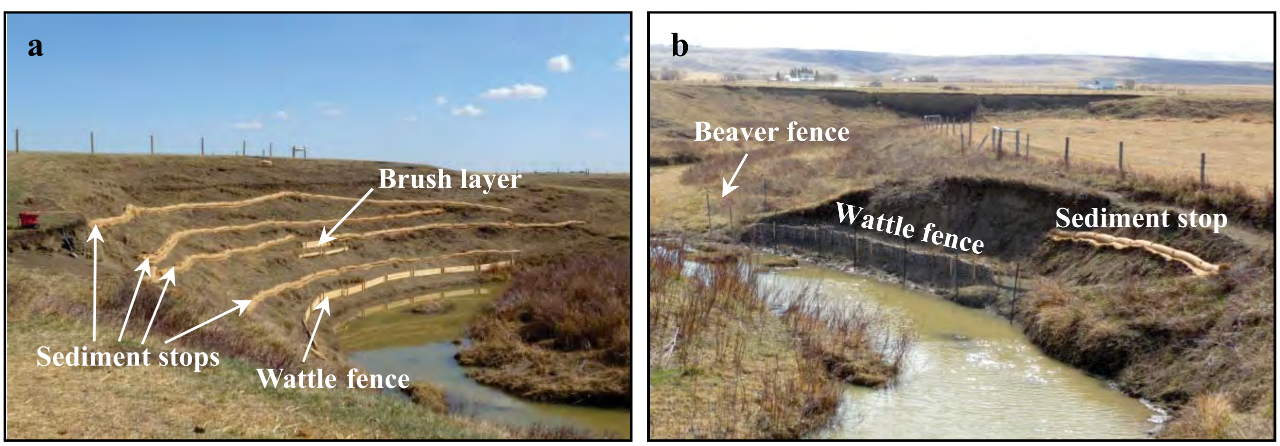

Figure 3.88. Bioengineering (a) Site 2 and (b) Site 3 constructed in April 2010 at the Wintering site.

3.8.2.4 Riparian Quality

The Alberta Riparian Habitat Management Society (i.e., Cows and Fish) carried out a visual riparian health assessments in 2007 and 2012 at the WIN site (Sub-section 2.11.1) in Pasture E. The surveys were carried out on June 13, 2007 and June 12, 2012. Both sides of IFC were surveyed between two endpoints (INF3U to INF3L) in both years (Figure 3.89). Because of the bioengineering demonstration sites constructed in 2010, the reach was divided into a west portion (INF4U to INF4L) and an east portion (INF5U to INF5L). Riparian health assessments were carried out for the three areas: whole site (INF3), western portion (INF4), and the bioengineering portion (INF5). The distance surveyed along the creek was 1.83 km and the riparian zone width, including both sides of the channel, ranged from 6 to 30 m with an average of 20 m. The total riparian area (i.e., polygon) surveyed was about 2.8 ha in size.

In addition to the Cows and Fish surveys, annual transect surveys were carried out from 2008 to 2012 (Sub-section 2.8.2). In 2008, 12 paired transects (Transects 1 to 12) were surveyed on either side and along the full length of IFC within Pasture E (Figure 3.89). Each transect consisted of two sub-transects, one on either side of the creek, for a total of 24 sub-transects. The 24 sub-transects varied in length from 2 to 30 m. The full set of transects was also surveyed in 2012. From 2009 to 2011, however, a random set of four transects was assessed each year (Table 3.58). These data are not presented in this report. Statistical analyses of changes in riparian community composition, species richness (SR), effective Shannon diversity (ED), and evenness (E), were carried out as described in Sub-section 2.11.2.

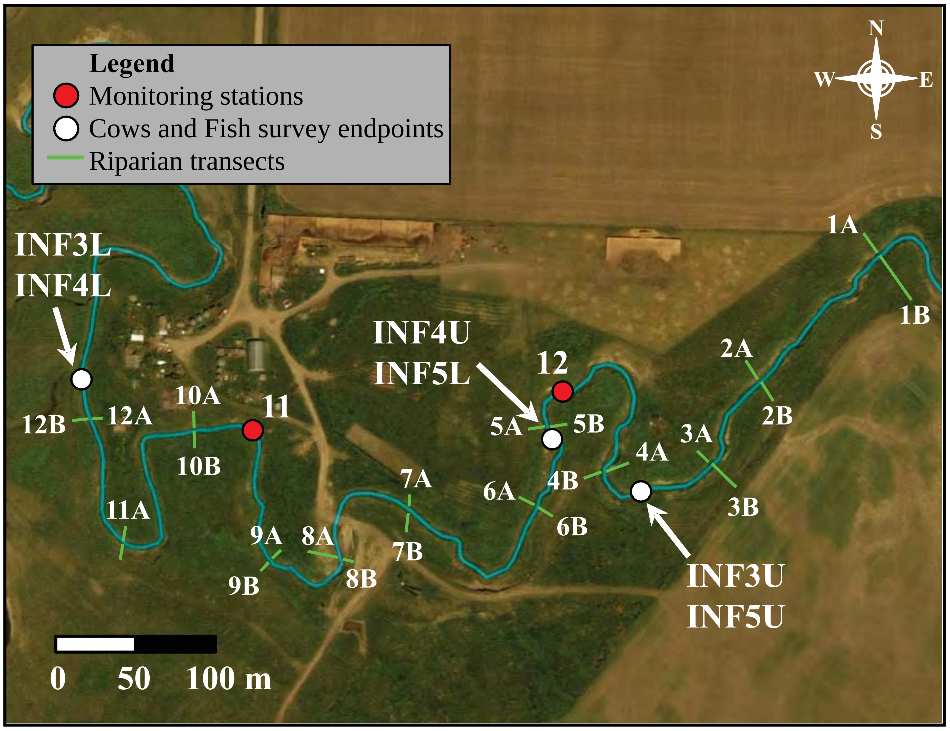

Figure 3.89. Location of the Cows and Fish riparian assessment endpoints, and the annual riparian survey transects, along Indianfarm Creek, in Pasture E, at the Wintering site.

Table 3.58. Riparian transect surveys carried out at the Wintering site from 2008 to 2012.

Survey date	Transects surveyed[z]
June 3 and 4, 2008	1 to 12
June 10, 2009	3, 5, 7, 9
June 9 and 10, 2010	1, 6, 10, 12
June 20, 2011	2, 4, 8, 11
June 18, 20, and 21, 2012	1 to 12

[z] Each transect consisted of two parts (a and b), one on either side of Indianfarm Creek.

3.8.2.5 Water Flow and Quality

Two instream water monitoring stations were installed at the WIN site in 2007. Station 12 was upstream, and Station 11 was downstream, of the old bedding site (Figure 3.85). Both stations were equipped with Isco water samplers and Station 12 was equipped with a Level TROLL to measure flow.

Five event types were defined for the samples: snowmelt, rainfall, base flow, dam release, and a flood that occurred on June 17, 2010. Base flow was considered low flow when no overland runoff occurred, which was checked against hydrographs, climate data, and field observations. Dam release occurred when water was released from Therriault Dam (Figure 3.3) to make room for snowmelt in the spring and/or to provide water for livestock in the north part of the watershed. The water quality data collected during the dam releases were similar to the base flow data, and therefore, the dam-release data were combined with the base-flow data for statistical comparisons. The flow that occurred during the flood on June 17, 2010 was higher than any flows that occurred throughout the study and during the pre-BMP phase. The water data collected during the flood period were not included because the pre- and post-BMP periods should have similar flow ranges when making statistical comparisons (Spooner et al. 1985) and because agricultural BMPs are not typically designed for, nor are effective during, extremely high-flow conditions.

Flows at Stations 11 and 12 were considered the same, or the difference between the two stations was too small to measure. Thus, water quality data were compared only on the basis of concentration at this site. The pre-BMP phase included data collected from March 6, 2007 to October 24, 2008 and the post-BMP phase included data collected from April 7, 2009 to June 27, 2012.

Water quality parameters were compared between the upstream and downstream stations using samples collected by the same method (Isco or grab sampled) on the same day at both stations. Statistical analysis was carried out for an upstream-downstream design (Sub-section 2.8.4).

Further details on water monitoring stations, sampling, flow measurements, laboratory analysis, and statistical analysis are presented in Sub-sections 2.6, 2.7, and 2.8.

3.8.3 Results and Discussion

3.8.3.1 Implementation of Beneficial Management Practices

The implementation and maintenance of the rotational grazing plan was successful during the post-BMP period. The plan had a tight schedule and the producer played a key role ensuring it was followed. Rotational grazing prevented the cattle from grazing the riparian pasture (Pasture E) during the spring period, and the overall time cattle were in the riparian pasture was reduced. Based on the management information collected in 2008, cattle had complete access to the riparian area for about 77% of the year and had access during most of the spring, which was typical management prior to the BMP (Table 3.55). After the BMPs were implemented, cattle had no access to the riparian area and IFC in the spring and the portion of the year in the riparian pasture was reduced to an average of 28%, ranging from 15% in 2009 to 40% in 2012. Furthermore, the producer reported that when in Pasture E, the cattle often preferred drinking from the off-stream watering system to drinking from the creek. This may suggest that not only did cattle spend less time in Pasture E during the post-BMP period, they spent even less time next to or in the creek because of the off-stream water source.

Pasture A, which contained the new winter bedding and feeding site, was an important part of the rotational grazing plan. This pasture and bedding area provided water and shelter for the cattle, as well as containment for cattle processing during calving and weaning. Pasture A was used more than any other pasture, at about 45% of the time on average during the post-BMP period. Because of the high use, future management considerations could include manure pack management in Pasture A.

The total cost of the BMP implementation and maintenance and the bioengineering was nearly $28,500 (Table 3.59). Of this total, 46% percent was for the bioengineering test sites. Bioengineering is considered more of a reclamation activity than a BMP. The cost of the infrastructure to relocate the winter bedding and feeding site and to implement the rotational grazing plan was $15,150. This included the installation of the two off-stream watering systems, and construction of the new winter bedding and feeding site, the new fences, and the portable windbreak. There was also a small amount of cost for maintenance in 2010, and for labour to maintain the rotational grazing plan, but the majority of the cost was the one-time payment for infrastructure. Future costs will likely be required for routine maintenance and repairs.

Table 3.59. Cost of beneficial management practices and bioengineering at the Wintering site.

Year	Item	Cost ($)	Labour (h)
2008	New bedding site: windbreak fence	2,600	
	New bedding site: barbwire fence (contract)	2,500	
	New bedding site: permanent water system	2,500	
	South pasture: barbwire fence (contract)	2,500	
	South pasture: Kelln solar water system	3,800	40
	Sub-total	**13,900**	**40**
2009	Portable windbreak	1,250	
	BMP maintenance and management	-	15
	Bioengineering[z]	$75	6
	Sub-total	**1,325**	**21**
2010	BMP maintenance and management	340	6
	Bioengineering[z]	12,883	14.5
	Sub-total	**13,222**	**20.5**
	Grand total	**28,448**	**81.5**

[z] Refer to Sub-section 3.8.2.3 for bioengineering details.

3.8.3.2 Riparian Quality

Cows and Fish assessment. Riparian health improved at the WIN site from an unhealthy rating (47% score) to a healthy with problems rating (60% score) (Table 3.60). The vegetation and the soil/hydrology ratings improved from 2007 to 2012, although they remained healthy with problems and unhealthy, respectively. Overall, the riparian area remained well vegetated from 2007 to 2012, with smooth brome grass and Kentucky bluegrass as 80% of the vegetative cover. Other findings included increased regeneration and establishment of preferred woody communities (e.g., willow species), decreased browsing pressure, and decreased human-caused bare ground along stream banks. Preferred woody plants (e.g., willows) were not well established in either year. However, signs of improved establishment of woody plants by 2012 suggest that the reduced grazing pressure in the riparian pasture had a positive effect.

The sub-portions of the full area assessed in 2012 had overall ratings of 62% for the INF4 and 70% for INF5, and thus, both areas were described as healthy but with problems. The stream crossing was identified as a factor contributing to alteration of the floodplain, and this contributed to the lower score for INF4. It was noted that cattle had easier access to the INF4 area compared to the INF5 area because the latter had steeper stream banks. It is likely that this also contributed to the lower rating in INF4 as compared to INF5.

Table 3.60. Summary of the Cows and Fish riparian health assessment carried out along Indianfarm Creek (INF3) at the Wintering site on June 13, 2007 and June 12, 2012.

	2007 assessment			2012 assessment			
	PST site	Max. score	Rating (%)[z,y]	PST site	Max. score	Rating (%)[z,y]	Health difference
Vegetation							
Vegetative cover of floodplain and streambanks	6	6		6	6		no change
Invasive plant species (cover)	2	3		2	3		no change
Invasive plant species (density distribution)	0	3		0	3		no change
Disturbance-caused undesirable herbaceous species	0	3		0	3		no change
Preferred tree and shrub establishment and regeneration	6	6		6	6		no change
Utilization of preferred trees and shrubs	0	3		1	3		improved
Live woody vegetation removal by other than browsing	na[x]	na		3	3		na
Decadent and dead woody material	3	3		3	3		no change
Vegetation rating	17	27	63	21	30	70	improved
Soil/hydrology							
Streambank root mass protection	0	6		0	6		no change
Human-caused bare ground	4	6		6	6		improved
Streambank structurally altered	0	6		2	6		improved
Human physical alteration to site	0	3		1	3		improved
Stream channel incisement	6	9		6	9		no change
Soil/hydrology rating	10	30	33	15	30	50	improved
Overall rating	27	57	47	36	60	60	improved

[z] Site score as a percentage of the maximum possible score.
[y] Healthy (80 to100%): Little or no impairment to riparian functions.
Healthy but with problems (60 to 79%): Some impairment to riparian functions due to human or natural causes.
Unhealthy (<60%): Impairment too many riparian functions due to human or natural causes.
[x] na = not applicable.

The adoption of the grazing rotation BMP plan and application of bioengineering were determined to have a positive impact on the riparian zone. In fact, the producer observed a noticeable improvement in Pasture E as early as 2010. However, challenges still exist at the site. For example, invasive species such as smooth brome grass and Kentucky bluegrass increased at the site, which may be a result of the decreased grazing pressure. The presence of invasive species may have prevented or limited the expansion of preferred trees and shrubs. Additional plantings of live stakes could be helpful; however, some control of the invasive grass species may be required.

Annual transect assessment. For plots at the Wintering site, a one-way PERMANOVA test showed that overall, communities were significantly different in at least two year-zone combinations. Pairwise comparisons between groups showed that communities were significantly different between 2008 and 2012 in both the riparian and transition zones, but not in the upland zone (Table 3.61). For upland plots at the WIN site, community differences between 2008 and 2012, although not statistically significant, were mostly attributable to an increase in the percent cover of Kentucky bluegrass, western snowberry, smooth brome, and prickly wild rose, and decreases in the percent cover of western wheatgrass and northern wheat grass (*Agropyron dasystachyum*) (in order of importance from most to least, for those species whose contribution to overall difference was greater than 4%). Community differences in the transition plots were mostly

Table 3.61. Analysis of differences in the overall plant communities (percent cover) between year (i.e., before and after BMP implementation) and vegetation zone combinations at the Wintering site. [z]

Overall model

Source	Sum of squares	F value	*P* value
Year×Zone	26.2	8.253	0.0001
Total	33.57		

Differences between Year×Zone combinations
Bonferroni-corrected P values

	2008 Upland	2008 Transition	2008 Riparian	2012 Upland	2012 Transition	2012 Riparian
2008 Upland	-	0.002	0.002	1.000	0.002	0.002
2008 Transition		-	0.002	0.062	0.002	0.002
2008 Riparian			-	0.003	0.002	0.002
2012 Upland				-	0.342	0.179
2012 Transition					-	0.002
2012 Riparian						-

[z] One-way PERMANOVA statistical test .

attributable to increases in percent cover of smooth brome, Kentucky bluegrass, and western snowberry, and decreases in percent cover of prickly wild rose, western wheatgrass, and quackgrass. For riparian plots, community differences were mostly attributable to increases in percent cover of smooth brome, Kentucky bluegrass, and western snowberry, sedge, and prickly wild rose, and a decrease in percent cover of narrow leaved willow (*Salix exigua*).

The interaction between year and zone was not significant for the analysis of ED and E, and was thus removed before the final analysis (Table 3.62). Zone was not a significant factor in the analysis of ED, but was a significant factor for E. There was a significant interaction between year and zone for SR. Species richness was significantly higher in 2012 (post-BMP) compared to 2008 (pre-BMP) for all three vegetative zones. Effective diversity was also significantly higher in 2012. In contrast, E was significantly lower in 2012 than in 2008, although the magnitude of this difference was not great.

Similar to the PST site (Sub-section 3.7), the increase in SR and ED were mostly attributable to invasive species such as Kentucky bluegrass and smooth brome, which colonized all three zones. It is difficult to interpret whether this was a beneficial change, because although increased diversity implies a healthier, more resilient ecosystem, invasive species can eventually out-compete other species, leading ultimately to lower diversity. However, there were also positive changes, including increases in desirable shrub species such as western snowberry (all three zones) and prickly wild rose (transition and riparian zones). The decrease in quack grass, a disturbance-related nuisance weed, in the transition zone was also a positive change; however, there were also decreases in native grass species such as northern wheatgrass (uplands zone) and western wheatgrass (uplands and transition zones). Similar to the PST site, there was a decrease in narrow leaved willow in the riparian zone, and this may have been due to stream bank erosion caused by extremely high flows in 2010 and 2011.

Table 3.62. Type 3 tests of fixed effects (year, zone) in the analysis of species richness (SR), effective diversity (ED), and evenness (E) at the Wintering site.[z]

Parameter	Effect	Zone	Year	LSM[y]
SR[x]	Year × Zone	Riparian	2008	4.8*a*
			2012	10.2*b*
		Transition	2008	7.2*a*
			2012	10.7*b*
		Upland	2008	7.9*a*
			2012	10.2*b*
ED[w,v]	Year		2008	3.9*a*
			2012	5.8*b*
	Zone			ns[u]
E[w,v]	Year		2008	0.59*b*
			2012	0.53*a*
	Zone	Riparian		0.64*c*
		Transition		0.56*b*
		Upland		0.49*a*

[z] Generalized linear model (with a Poisson error distribution and log link function) used rather than a general linear model.
[y] LSM = least square means.
[x] Means for a give parameter and zone (i.e., 2008 vs. 2012) followed by the same letter are not significantly different ($P < 0.1$).
[w] Year × Zone interaction was not significant.
[v] Means for year or zone followed by the same letter are not significantly different ($P < 0.1$).
[u] ns = not significant.

The alteration of grazing practices appeared to impact the WIN vegetation composition. The increased presence of invasive and native species was likely impacted by the exclusion and grazing BMPs. However, it could take years for the site to reach a stable vegetative community through the process of succession, and it is unknown whether invasive or native species would eventually dominate. Although it is difficult to interpret from this analysis whether the vegetation composition changed in positive or negative ways, given the fact that Cows and Fish indicated an improvement, it is recommended that exclusion from the riparian zone during times of sensitive vegetative growth (e.g., spring) continue at this site.

3.8.3.3 Bioengineering

Of the 200 willow and cottonwood cuttings planted at Site 1 in May 2009, none survived by 2012. By the end of July 2009, a majority of the cuttings (119 stakes) were still alive. However, by September 2010 none of the cottonwood had survived and only 5% of the original 160 willow cuttings were still alive. Most of the willow cuttings were actually missing altogether by 2012. This was likely due to high spring flows and flooding in 2010 and 2011. Also, in 2012 there was an increase in beaver activity along this stretch of IFC and remaining willows may have been harvested by the beavers.

In contrast to Site 1, Sites 2 and 3 were very successful after construction in spring 2010. With the exception of an area that slumped at Site 2, and some missing willows from the wattle structure at Site 3, both sites withstood the high spring flows and runoff events in 2010 and 2011. Both sites withstood several high flow events in spring 2010 and were nearly submerged during the high-flow event on June 17, 2010. The live cuttings grew shoots about 0.6 m in the first year, likely attributable to the good moisture conditions during the growing season in 2010. Of the total number of live cuttings planted in 2010, not including the cuttings used in the bioengineering structures, there was a 75% survival rate in 2011 and a 45% survival rate in 2012. These survival rates were very good considering that 15 to 25% survival rates are considered successful for this ecoregion (personal communication, Tim Romanow, Executive Director, Milk River Watershed Council Canada). Images taken at the photo points highlight the successful growth and establishment of the cuttings at these sites (Figure 3.90).

3.8.3.4 Water Flow and Quality

Water flow. Flow was strongly related to precipitation, with the lowest flows in the driest years of 2007 and 2012, and the highest flows in the wettest years of 2010 and 2011 (Table 3.63, Subsection 3.2). The largest flow peaks in the study occurred during rainfall runoff from May 27 to 30, 2010, and from June 17 to 19, 2010 (Figure 3.91b). Annual flows in 2010 and 2011 were 7- to 54-fold greater than in other four years (Table 3.63). Thus, the average annual flow was about seven-fold greater during the post-BMP period than during the pre-BMP period. These differences in annual flow were the result of differences in the amount and distribution of precipitation. They were not a consequence of the BMPs, which were not designed to alter hydrology at this site.

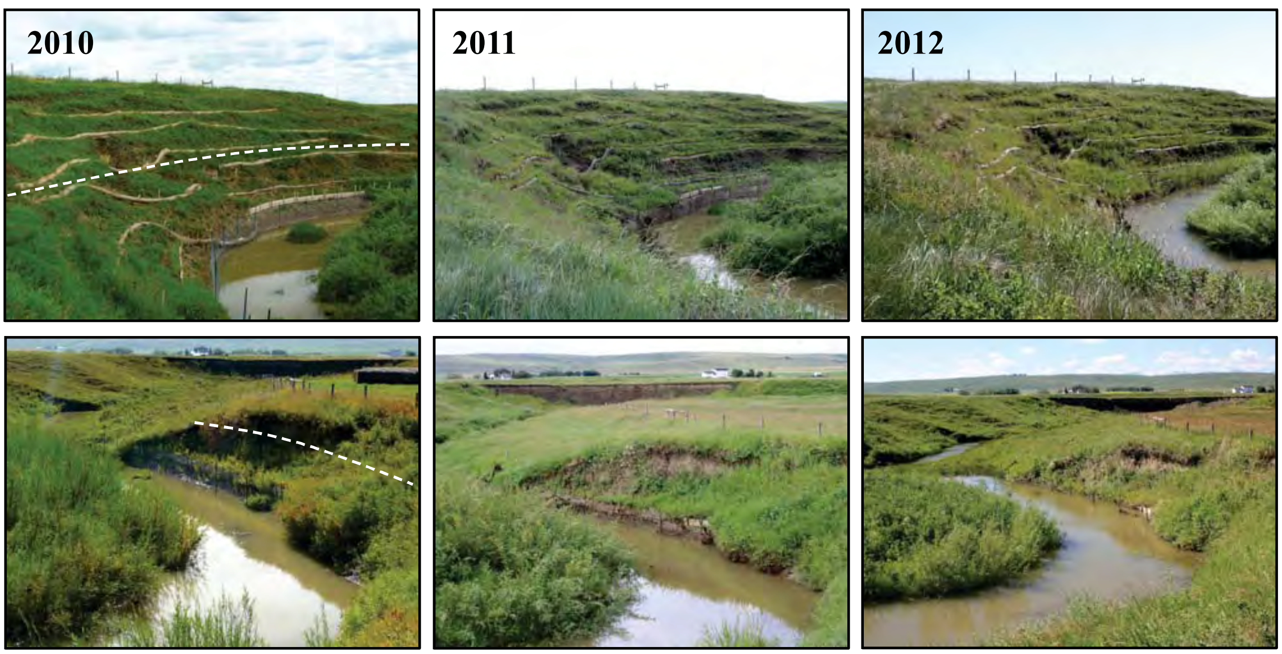

Figure 3.90. Vegetative establishment at the bioengineering Site 2 (top images) and Site 3 (bottom images) from 2010 to 2012 at the Wintering site. The white dashed lines indicate the approximate high-water level in June 2010.

Table 3.63. Annual flow and proportions of flow attributed to snowmelt and rainfall plus base flow (with dam release and flood included) runoff at the Wintering site from 2007 to 2012.

Year	Flow ($m^3 yr^{-1}$)	Proportion from snowmelt (%)	Proportion from rainfall and base flow (%)
2007	319,154	21	79
2008	2,428,580	15	85
2009	1,455,733	59	41
2010	17,337,780	3	97
2011	17,212,974	33	67
2012	708,669	47	53

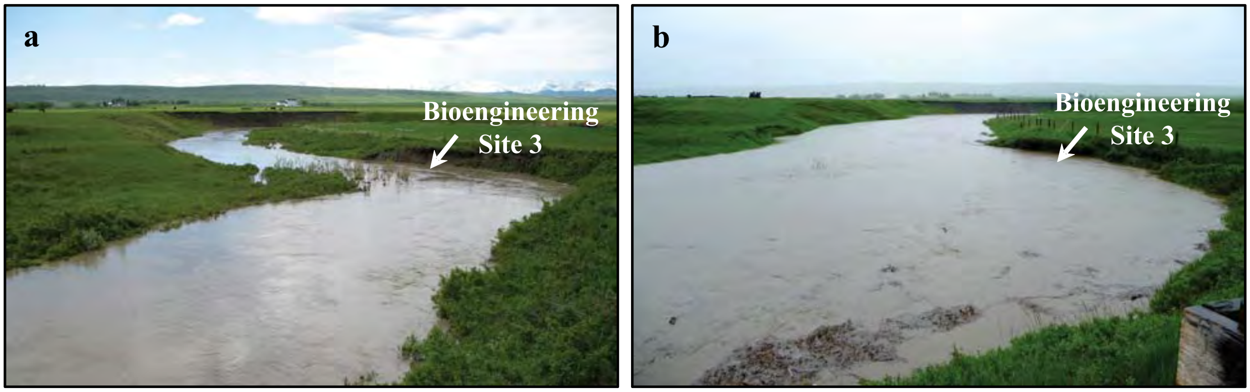

Figure 3.91. Near peak flow in Indianfarm Creek on (a) June 12, 2008 and (b) June 17, 2010 viewed downstream at Station 12.

Flow during most study years was dominated by rainfall runoff and base flow, with the exception of 2009, which had nearly 60% of flow during the snowmelt period (Table 3.63). On average, about 30% of the flow occurred during snowmelt from 2007 to 2012. The annual flow in 2011 was similar to 2010; however, the portion of flow during snowmelt was higher in 2011, at 33%, compared to 3% in 2010. Precipitation from January to March was about twice as high in 2011 compared to 2010 (Sub-section 3.2).

General water quality observations. Generally, the concentrations of TN, TP, TSS, and *E. coli* varied similarly between the upstream Station 12 and the downstream Station 11 (Figure 3.92). The length of the creek between the two stations was about 450 m, which was a relatively short distance compared to the total length of IFC (about 57 km). Total N, TP, and TSS peaked in the mid to late spring in all years, particularly for the three years (2008, 2010, and 2011) with the highest annual flow values (Figure 3.92a,b,c; Table 3.63). In relative comparison, there were no major concentration peaks in the years that had much lower annual flows in the creek (2007, 2009, and 2012). The concentration pattern of *E. coli* was more constant among years and not as influenced by different annual flows. *Escherichia coli* concentrations were highest during rainfall runoff events and lowest during snowmelt events at both stations (Table 3.64). Concentration of *E. coli* increased during the spring and peaked generally in May or June, after which concentrations deceased during the summer and fall (Figure 3.92d). This seasonality effect on *E. coli* has been found in other agricultural watersheds in Alberta (Lorenz et al. 2008).

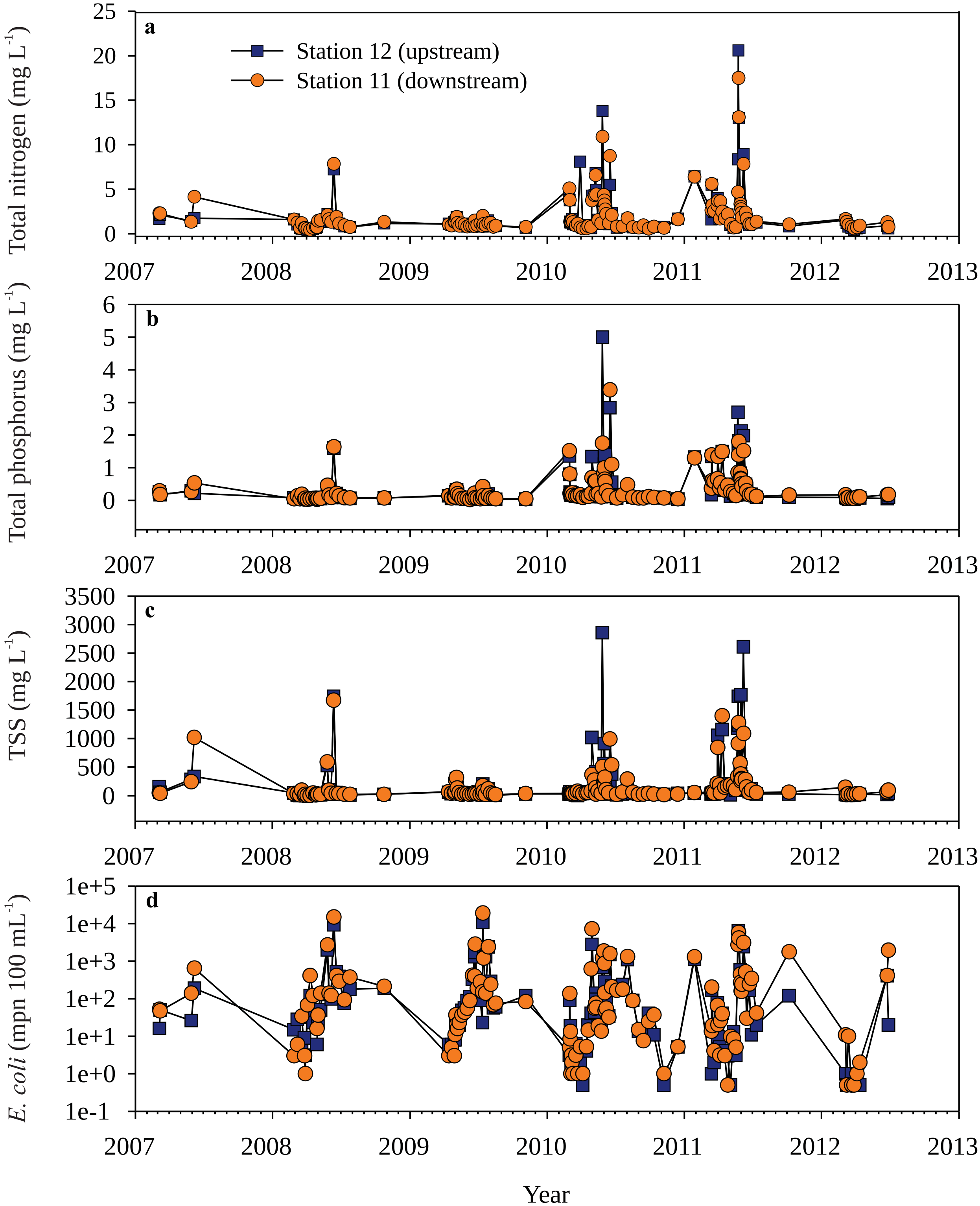

Figure 3.92. Concentrations of (a) total nitrogen, (b) total phosphorus, (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) at the upstream and downstream monitoring stations at the Wintering site from 2007 to 2012.

he 6-yr (pre- and post-BMP periods) average concentration of most parameters was highest during rainfall events. For the two stations, concentrations in the creek during rainfall events were 1.3- to 29-fold higher than during snowmelt and base flow events for TN, ON, NO_3-N, TP, PP, TSS, and *E. coli* (Tables 3.64 and 3.65). Concentrations were particularly high during rainfall events for *E. coli*. Exceptions to this observation included NH_3-N and TDP, which had similar concentrations for rainfall and snowmelt. Average pH was similar among the three event types and EC was the highest during snowmelt. Also, on average for all events, about 64% of TN was in ON form and about 66% of TP was in PP form. This reflects the high sediment content in IFC.

BMP effects on water quality. The concentration of several parameters increased from upstream to downstream during the pre-BMP period. For all event types, average increases of 16% for TN, 17% for ON, 33% for NH_3-N, 56% for *E. coli*, 18% for TP, 25% for TDP, 25% for PP, and 20% for TSS were observed (Tables 3.64 and 3.65). Nitrate N, pH, and EC concentrations changed very little between the two stations during the pre-BMP period.

Table 3.64. Average nitrogen and *Escherichia coli* concentrations for the upstream (Station 12) and downstream (Station 11) stations in the pre- (2007 to 2008) and post-BMP (2009 to 2012) periods, and the average differences between the two stations in the pre- and post-BMP periods at the Wintering site.[z]

	TN		ON		NO_3-N		NH_3-N		*E. coli*	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Station	($mg\ L^{-1}$)								($mpn\ 100\ mL^{-1}$)	
Snowmelt (n=15 pre, 38 post)[y]										
Downstream	1.11	2.01	0.91	1.44	0.09	0.33	0.08	0.21	78	54
Upstream	0.95	2.09	0.77	1.57	0.09	0.30	0.06	0.20	31	48
Difference[x]	*0.16*	*-0.08*	*0.14*	*-0.13*	*0*	*0.03*	*0.02*	*0.01*	*47a*	*6b*
Rainfall (n=5 pre, 41 post)[y]										
Downstream	3.42	3.18	3.06	1.46	0.21	1.54	0.12	0.15	3726	1509
Upstream	2.88	3.45	2.52	1.71	0.21	1.55	0.12	0.17	2329	1133
Difference	*0.54*	*-0.27*	*0.54*	*-0.25*	*0*	*-0.01*	*0*	*-0.02*	*1397a*	*376b*
Base flow (n=6 pre, 25 post)[y]										
Downstream	1.24	0.91	1.16	0.79	0.03	0.07	0.03	0.03	249	98
Upstream	1.17	0.90	1.09	0.79	0.03	0.07	0.03	0.03	242	115
Difference	*0.07*	*0.01*	*0.07*	*0*	*0*	*0*	*0*	*0*	*7*	*-17*
Active runoff – snowmelt plus rainfall (n=20 pre, 79 post)[y]										
Downstream	1.69	2.62	1.45	1.45	0.12	0.95	0.09	0.18	1151	809
Upstream	1.43	2.80	1.21	1.64	0.12	0.95	0.08	0.18	707	611
Difference	*0.26a*	*-0.18b*	*0.24a*	*-0.19b*	*0*	*0*	*0.01*	*0*	*444a*	*198b*
All events (n=26 pre, 104 post)[y]										
Downstream	1.59	2.21	1.38	1.30	0.10	0.74	0.08	0.14	916	638
Upstream	1.37	2.34	1.18	1.44	0.10	0.74	0.06	0.15	586	492
Difference	*0.22a*	*-0.13b*	*0.20a*	*-0.14b*	*0*	*0*	*0.02*	*-0.01*	*330a*	*146b*

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonium nitrogen, *E. coli* = *Escherichia coli*.
[y] n values shown are maximums. In some cases, the n value may be less due to missing data.
[x] Average differences per parameter and event type followed by letters are significantly different at $P < 0.1$.

Table 3.65. Average phosphorus concentration, total suspended solids concentration, and electrical conductivity for the upstream (Station 12) and downstream (Station 11) stations in the pre- (2007 to 2008) and post-BMP (2009 to 2012) periods, and the average differences between the two stations in the pre- and post-BMP periods at the Wintering site.[z]

	TP		TDP		PP		TSS		pH		EC	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Station	------------------------------------ (mg L^{-1}) ---------------------------------										(μS cm^{-1})	
					Snowmelt (n=15 pre, 38 post)[y]							
Downstream	0.089	0.403	0.032	0.198	0.057	0.205	29	133	8.29	8.22	705	524
Upstream	0.069	0.386	0.029	0.191	0.041	0.195	26	124	8.29	8.23	685	512
Difference[x]	*0.020*	*0.017*	*0.003*	*0.007*	*0.016*	*0.010*	*3*	*9*	*0*	*-0.01*	*20*	*12*
					Rainfall (n=5 pre, 41 post)[y]							
Downstream	0.613	0.516	0.096	0.183	0.517	0.333	725	257	8.22	8.30	500	491
Upstream	0.521	0.720	0.100	0.155	0.422	0.566	597	474	8.24	8.32	515	488
Difference	*0.092*	*-0.204*	*-0.004b*	*0.028a*	*0.095*	*-0.233*	*128*	*-217*	*-0.02*	*-0.02*	*-15*	*3*
					Base flow (n=6 pre, 25 post)[y]							
Downstream	0.111	0.091	0.037	0.012	0.074	0.079	32	39	8.27	8.38	523	578
Upstream	0.109	0.087	0.039	0.012	0.070	0.076	31	37	8.30	8.41	520	565
Difference	*0.002*	*0.004*	*-0.002*	*0*	*0.004*	*0.003*	*1*	*2*	*-0.03*	*-0.03*	*3*	*13*
					Active runoff – snowmelt plus rainfall (n=20 pre, 79 post)[y]							
Downstream	0.22	0.46	0.17	0.27	0.05	0.19	203	198	8.27	8.26	654	507
Upstream	0.18	0.56	0.14	0.39	0.05	0.17	169	306	8.28	8.28	643	499
Difference	*0.04*	*-0.10*	*0.03*	*-0.12*	*0*	*0.02*	*34*	*-108*	*-0.01*	*-0.02*	*11*	*8*
					All events (n=26 pre, 104 post)[y]							
Downstream	0.20	0.37	0.05	0.15	0.15	0.23	164	160	8.27	8.29	624	524
Upstream	0.17	0.45	0.04	0.13	0.12	0.31	137	241	8.28	8.31	614	515
Difference	*0.03*	*-0.08*	*0.01*	*0.02*	*0.03*	*-0.08*	*27*	*-81*	*-0.01*	*-0.02*	*10*	*9*

[z] TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, pH= potential hydrogen, EC = electrical conductivity.
[y] n values shown are maximums. In some cases, the n value may be less due to missing data.
[x] Average differences for pre- and post-BMP phases per parameter and event type followed by letters are significantly different at $P < 0.1$.

During the post-BMP period, the concentration of several parameters decreased (3 to 34%) or remained unchanged from upstream to downstream when averaged for all events (Tables 3.64 and 3.65). The parameters that increased in concentration from upstream to downstream during the pre-BMP period either increased to a lesser extent (*E. coli* and TDP) or decreased from upstream to downstream (TN, ON, NH_3-N, TP, PP, and TSS) during the post-BMP period. This would suggest that water quality improved during the post-BMP period compared to the pre-BMP period, but not all comparisons were statistically significant. By comparing the upstream-downstream differences between the pre- and post-BMP periods, three parameters (TN, ON, and *E. coli*) were significantly improved for active runoff (snowmelt plus rainfall) and all events combined (Table 3.64). The particulate forms of the nutrients (ON, PP) were decreased more in the post-BMP period than the dissolved forms (NO_3-N, NH_3-N, and TDP). Overall, the concentration change from upstream to downstream for NH_3-N was reduced slightly. There was no change for NO_3-N and TDP in the post-BMP period. The reduction in TSS in the post-BMP period, although not significant, supports the greater influence of the BMPs on the particulate, as opposed to the dissolved forms of nutrients.

For rainfall events, the average concentration of most parameters either increased (18 to 60%) or remained unchanged from upstream to downstream during the pre-BMP period for rainfall events (Tables 3.64 and 3.65). Similar results were observed for the snowmelt events during the pre-BMP period. The concentration of most parameters decreased from upstream to downstream for rainfall events during the post-BMP period; whereas, concentrations for snowmelt events still remained unchanged or increased to a lesser extent (2 to 6%) compared to the pre-BMP period. However, for most parameters, concentration changes from upstream to downstream between the pre- and post-BMP periods were not significantly different, except for *E. coli*, which had significantly less contribution during the post-BMP period for rainfall and snowmelt events. In contrast, TDP concentration had a significantly greater contribution during the post-BMP period for rainfall events compared to the pre-BMP period.

During base flow, the average concentration of most parameters either remained unchanged or increased slightly (2 to 6%) from upstream to downstream during the pre-BMP period (Tables 3.64 and 3.65). There was no indication that water quality improved during base flow in the post-BMP period. The only exception may have been for *E. coli*, which increased 6% during the pre-BMP period and decreased by 15% during the post-BMP period. However, *E. coli* concentration changes from upstream to downstream between the pre- and post-BMP periods were not significantly different. Because of the lack of major precipitation and active runoff, it was not surprising to observe less change between upstream and downstream and minimal, if any, BMP effects on water quality during base flow compared to rainfall and snowmelt events.

The significant water quality improvements (TN, ON, *E. coli*) observed in this study may be attributable to the cattle management BMPs. The relocation of the winter bedding and feeding site away from the creek may have resulted in less manure accumulation and riparian zone degradation adjacent to the creek, which would have decreased nutrient content in runoff waters. The establishment of the riparian pasture (i.e., Pasture E) and the application of rotational grazing excluded cattle from the riparian area during the more sensitive spring season, and reduced overall grazing time per year in the riparian pasture, would have had a similar effect. This is consistent with the observed reductions in nutrients, *E. coli*, and sediment concentrations in the post-BMP period. The fact that other parameters, such as pH and EC, were not expected to change as a result of the BMPs, and indeed did not change, is an indication that the water quality differences observed were a result of BMP implementation.

3.8.4 Conclusions

- The relocation of the winter bedding and feeding site, creation of a riparian pasture, and use of a rotational grazing plan and off-stream watering reduced the time cattle spent in the riparian pasture by two-thirds overall, and allowed total exclusion during the more sensitive spring period. When the cattle were in the riparian pasture, they tended to drink from the off-stream watering system instead of the creek, presumably further reducing the time spent by cattle in the riparian area. The producer was satisfied with the implementation, management requirements, and performance of the BMP.

- The BMP cost $15,225 and required 61 h to implement along with maintenance. Nearly all of the costs were during the implementation of the BMPs, and most of the cost (>90%) was for the installation of the two off-stream watering system, construction of the new winter bedding and feeding site, and new fences.

- Based on the Cows and Fish assessment, riparian quality improved at the WIN site. The overall riparian function rating increased from unhealthy in 2007 to healthy with problems in 2012, suggesting a positive effect of the BMPs. Improvement was observed for the individual vegetation and soil/hydrology factors as well. Other findings included increased regeneration and establishment of preferred woody communities, decreased browsing pressure, and decreased human-caused bare ground along the stream bank.

- The riparian transect surveys showed there was an increase in species richness and effective diversity in 2012 as compared to 2008; however, this was mostly a result of colonization by invasive species. The exclusion and rotational grazing BMP appeared to have a positive impact on the WIN riparian vegetation.

- Two of the three bioengineering demonstration sites were successful. The bioengineering techniques used on two highly eroded sites were expensive and labour intensive, but survived very high flows in IFC in 2010. Live stakes grew well and survival rate was high. Even though bioengineering was successful in stabilizing these eroded sites, the high cost for such a small area may reduce its applicability.

- The relocation of the winter bedding and feeding site, establishment of a riparian pasture, and use of a rotational grazing plan improved water quality in the post-BMP period compared to the pre-BMP, with significant improvement in the concentration of TN, ON, and *E. coli*. Water quality improvements tended to be greater during rainfall events compared to snowmelt events, and BMP effects were not observed during base-flow events.

- The results support the hypothesis that relocation of the winter bedding and feeding site, and using a rotational grazing plan to reduce the time cattle spent in the riparian pasture, would improve water quality. The hypotheses that particulate forms of nutrients would be affected more by the BMPs than dissolved forms, and that rotational grazing would improve riparian health, were also supported.

3.9 South Manure Field

3.9.1 Introduction

The SMF site was selected as a potential manure and cattle management BMP site. The site was an annually cropped field that routinely received feedlot cattle manure and was grazed in the fall by cattle. A drainage tributary bisected the field and the intended BMP plan was to improve the quality of runoff water draining from the field into the tributary. Immediately upstream from this monitored site was a cattle wintering and calving pasture, where cattle had direct access to the tributary. The tributary was instrumented with two water monitoring stations, which were upstream and downstream relative to the field.

Unfortunately, due a number of factors that are discussed below in Sub-section 3.9.2.2, the intended BMPs could not be implemented at this site. Even though BMPs were not implemented, the collection of water quality data for 6 yr offered an opportunity to assess water quality changes in a reach of a small tributary, which received runoff directly from adjacent cropped fields and was downstream from a cattle wintering and calving pasture.

3.9.2 Methods

3.9.2.1 Site Description and General Management

The SMF site was in the central part of the watershed (Figure 3.3) in the upper region (Figure 3.3). The site had a small tributary, which flowed from west to east in the northern part of the section (Figure 3.93). The tributary entered a wetland area on the east-central side of the section and eventually flowed into IFC, which was about 1 km further east. Most of the section south of the tributary was an annually cropped field. The area northeast of the tributary was also an annually cropped field and this field extended into the next section of land to the north. The drainage area to the tributary between the two water monitoring stations was 57 ha in size, with 19 ha on the north side and 38 ha on the south side (Figure 3.93). The drainage area north of the tributary had a 2 to 5% slope with a south facing aspect, and the drainage area to the south had a more complex landform with slopes that ranged from 0 to 5%.

In the northwest quarter section upstream Station 17, there was a wintering and calving pasture (Figure 3.93). The tributary was connected to a couple of dugouts in the pasture and cattle in this area had direct access to the tributary. The drainage area to Station 17 was estimated at about 74 ha in size (Jedrych et al. 2013). About half of this area was occupied by the wintering and calving pasture and the drainage channel upstream and around Station 17 appeared to be more degraded (i.e., more stream bank erosion and less riparian vegetation) than the channel between Stations 17 and 18.

The north-side drainage area was within the DVG1/U1h soil landscape model as described by AGRASID (Alberta Soil Information Centre 2013). The soil in this model is an Orthic Black Chernozem, and includes a Dunvagian soil series, with well drained characteristics. The landform in the model is described as undulating, high relief with a limiting slope of 4%, and parent material is described as medium-textured till. The south-side drainage area was within the DVFS13/H1l soil

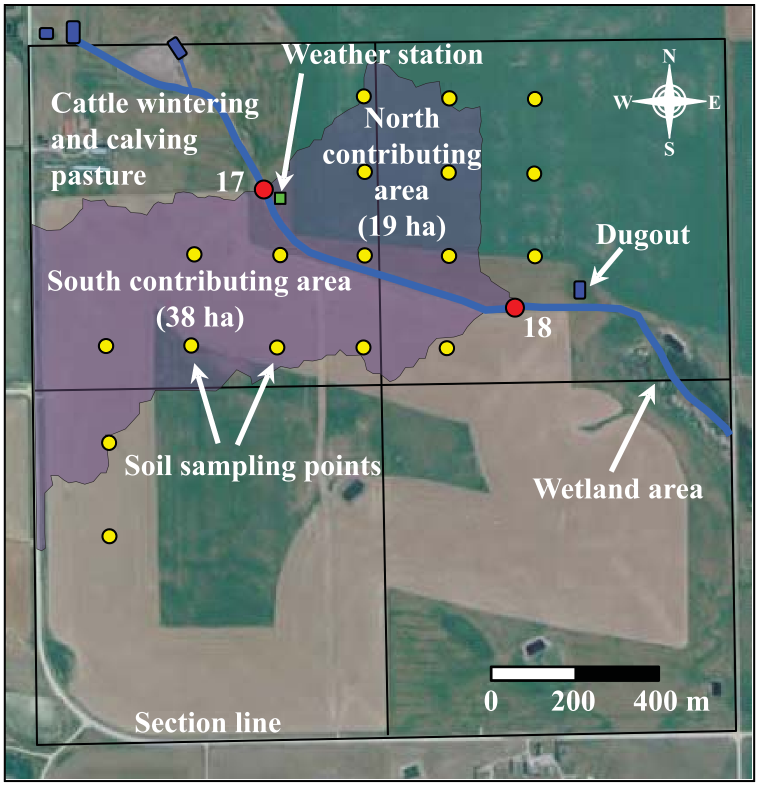

Figure 3.93. The drainage area to the channel between Stations 17 (upstream) and 18 (downstream) at the South Manure Field.

landscape model (Alberta Soil Information Centre 2013). The soils in this model are Orthic and Gleyed Rego Black Chernozems, and include co-dominant (40% each) Dunvagian and Fish Creek soil series and a significant (20%) Misc. SAL-ZBL soil series, with well to imperfectly drained characteristics. The landform in the model is described as hummocky, low relief with a limiting slope of 6%, and parent material includes medium-textured till, fine-textured water laid sediment, and undifferentiated material. The surface soil had a clay-loam texture (41% sand, 31 % clay), pH of 6.5, electrical conductivity of 0.9 dS m^{-1}, 5000 mg kg^{-1} TN, 1085 mg kg^{-1} TP, and 11% organic matter (Appendix 4).

The fields on both sides of the tributary were rented by the cooperating producer during the study. Agricultural practices carried out for annual crop production were generally the same on both sides of the drainage channel. Crops included cereals and canola during the study (Table 3.66). Fertilizer (mainly N) was usually applied with the seed and crops were sprayed with herbicides as required to control weeds.

Solid cattle manure was usually applied once every 3 to 4 yr at the site. Manure was last applied to the north field in fall 2006 and was not applied again on this side of the drainage channel during the study. In 2006, manure was applied in small piles throughout the field (Figure 3.94a) and leveled with a cultivator by skimming the surface without incorporation. In 2008, manure was stockpiled in the northwest corner of the southwest quarter section, and was within the far southern

Table 3.66. Agronomic management practices at the South Manure Field from 2008 to 2011.

Year	Field	Crop	Seeding date	Harvest date	Yield (Mg ha^{-1})	Fertilizer N	P	K	S
						----------	(kg ha^{-1})	----------	
2007	north	barley	na	na	na	na	na	na	na
	south	na	na	na	na	na	na	na	na
2008	north	barley grain	mid-May	Sep 15	5.38	90	-	-	-
	south	barley grain	mid-May	Sep 15	5.38	90	-	-	-
2009	north	barley grain	May 14	Sep 10	5.10	101	-	-	-
	south	barley grain	May 14	Sep 10	5.10	101	-	-	-
2010	north	canola	May 7	Nov 6-7[z]	1.57[y]	87[x]	1[x]	49[x]	-
	south	barley grain	Apr 16	Sep 13	1.61[y]	87[x]	1[x]	49[x]	-
2011	north	wheat	May 6	Sep 22	3.50	90	20	-	-
	south	canola	Jun 12	mid-Sep	3.50	90	20	-	-
2012	north	barley grain	May 4	Sep 4	3.60	100	-	-	-
	south	barley grain	May 4	Sep 4	3.60	100	-	-	-

[z] Swathed on September 30, but because of wet fall conditions, canola was not combined until November.
[y] Lower than anticipated yield due to hail damage to crop on August 3, 2010.
[x] Fertilizer 25-0-20 (67 kg ha^{-1} N) was applied with the seed and Nutri Boost (22-9-18) and 28-0-0 were applied at the same time as herbicide application at 7 and 13 kg ha^{-1} N, respectively.

part of the drainage area (Figure 3.93). The manure was stockpiled for a short time prior to application to areas south of the drainage channel. No manure was applied in 2009. In fall 2010, only a small amount of manure was applied in the southwest corner of the southwest quarter section, outside of the drainage area, before the operation was stopped due to snow, and no further manure was applied in 2010. In fall 2011, manure was stockpiled northwest of Station 17. However, the manure was not applied because a custom manure applicator was not available prior to the onset of winter conditions.

Cattle typically fall grazed in the fields after harvest. A barbwire fence along the south side of the tributary was used to manage cattle between the north and south sides of the tributary. In 2008, 140 head of cattle grazed on the north side of tributary from October 18 to November 18. Piles of chaff, which is the crop residue remaining after thrashing, were left in the field (Figure 3.94b) and water was provided from a dugout east of Station 18 (Figure 3.93). The dugout was fenced and cattle had access to water from a trough with a solar powered pump. In 2009, 78 head of cattle grazed from November 6 to December 2. Fall grazing by cattle did not occur in 2010 because of early snow and wet conditions. In fall 2011 and early 2012, cattle were grazed in the north field. Extended grazing was practiced using hay bales that were unrolled in swaths in the field (Figure 3.95a). A portable windbreak was also placed on the north side of the tributary between the two monitoring stations (Figure 3.95b). Bedding that was applied at the windbreak was removed with manure and stockpiled nearby.

Figure 3.94. The field on the north side of the tributary at the South Manure Field showing (a) manure piles in fall 2006 and (b) chaff piles in fall 2008.

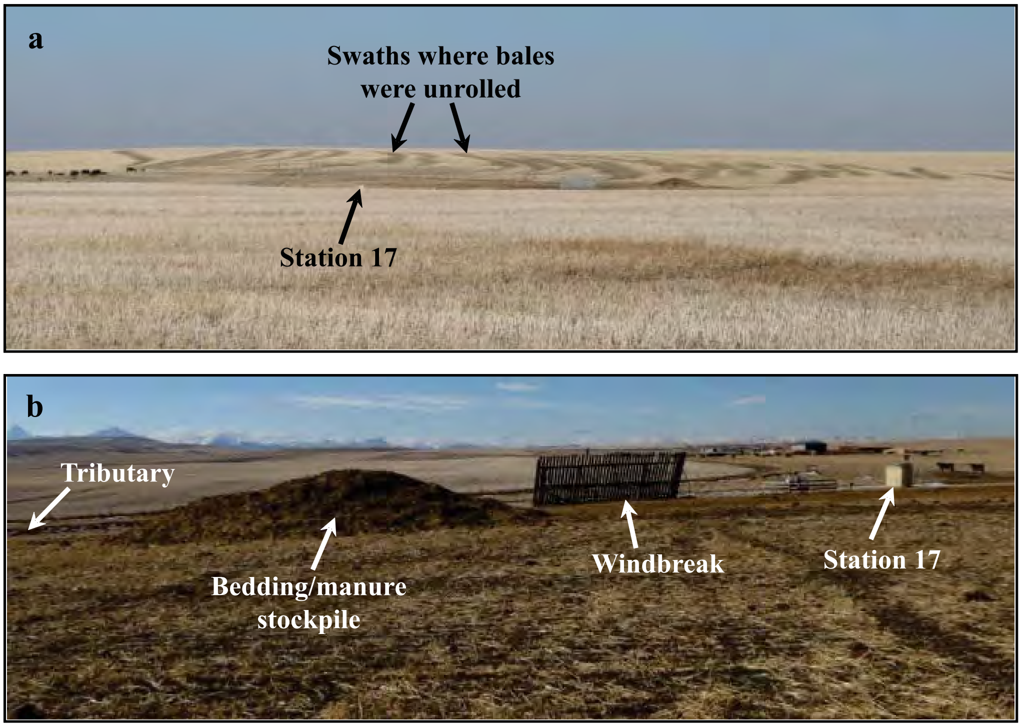

Figure 3.95. South Manure Field extended grazing season showing (a) unrolled bale swaths in the distance as viewed to the north and (b) portable wind shelter and bedding/manure pile in field north of drainage channel on February 2, 2012.

3.9.2.2 Beneficial Management Practices Plan

The intended BMPs included (1) applying a 30-m setback during manure application, (2) adopting a nutrient management plan, (3) using a different method to apply manure, (4) widening the grass buffer zone along the tributary, and (5) using distribution tools to encourage cattle to spend less time near the tributary during fall grazing.

Initially, part of the BMP plan included changing manure application from fall to spring application to avoid having manure on the soil surface during spring snowmelt. Typically, manure was applied once every 3 yr at this site, with the most recent application in fall 2006. Therefore, the next application would have been in fall 2009. The plan was to not apply manure in fall 2009, but rather in spring 2010. However, the producer preferred to apply manure in the fall because of concerns of not enough time to apply manure and soil compaction in the spring. It was also recognized that spring application of manure without incorporation may be a greater water quality risk than fall application. Manure is not usually incorporated in the Pincher Creek area because of the high risk of wind erosion of soil. As it turned out, no manure was applied to this site on the north side of the drainage channel during the monitoring period from 2007 to 2012.

A portable windbreak was provided as part of the cattle distribution BMP in 2009. The producer placed the windbreak downstream from Station 18 and outside of the drainage area. No cattle grazed in fall 2010. In fall 2011 and in early 2012, the windbreak was placed next to the drainage channel near Station 17 (Figure 3.95b) and windbreak was likely ineffective at detracting cattle away from the channel. Therefore, the use of the windbreak as a BMP only occurred in 2009.

A nutrient management plan was developed for 2010 using soil-test results from fall 2009 and the AFFIRM program (AFRD 2005b). However, the producer routinely used a consulting company to obtain crop nutrient recommendations, and these were the recommendations the producer preferred to use. The purpose of the nutrient management plan was to determine manure and fertilizer application rates, but no manure was applied during the 6-yr monitoring period.

If the BMPs were implemented in fall 2009 and maintained until the end of the study period as originally planned, the estimated cost would have been about $3200. This estimate included $2500 for a windbreak, $90 for salt blocks, and $610 for soil nutrient analysis. Total labour may have been about 25 h, including time for soil sampling, developing a nutrient management plan, and managing the portable windbreak.

As indicated in the introduction and for the reasons described above, the intended manure and cattle BMPs were not implemented and so could not be tested at this site.

3.9.2.3 Soil Sampling

Soil characterization samples (Sub-section 2.9) were collected on October 16, 2008. Agronomic samples (0- to 15-cm) were collected annually from 2007 to 2012. In most years, agronomic samples were collected in the spring and in the fall, except in 2010 when samples were only collected in July, and in 2012 when samples were collected only in the spring. Soil samples were not collected in fall 2010 due to a delayed harvest and poor weather conditions. In the first 2 yr (2007 and 2008), agronomic samples were collected only on the north side of the tributary using nine sampling points. In 2009, nine sampling points were added on the south side of the tributary. Agronomic soil sampling points were arranged on a 200- by 200-m grid (Figure 3.93). In 2011, two sets of agronomic samples were collected in the spring: one set before seeding on May 5 and a second set after seeding on June 29.

Soil-test samples (0 to 60 cm) were collected only once (October 2009) at this site for the purpose of developing a nutrient management plan as a planned BMP. These samples were collected along transects (Sub-section 2.9), using four transects in the northwest quarter section, three transects in the southeast quarter section, and five transects in each of the northeast and southwest quarter sections. Composite samples were prepared for each quarter section and sent to the lab for analyses.

3.9.2.4 Manure Sampling

Manure was sampled only once at the SMF site during the project. Samples were collected from six locations in each of two stockpiles of solid beef manure in the feedlot pens on September 1, 2010, for a total of 12 samples. At each location, three samples were collected and mixed into a composite sample, which was subsampled (1 kg) for water and nutrient analysis (Sub-section 2.10).

3.9.2.5 Water Flow and Quality Sampling

This site was equipped with two circular flumes and automatic Isco water samplers (Sub-sections 2.6, 2.7, and 2.8). The circular flumes were placed in the tributary, with Station 17 upstream of the drainage area and Station 18 downstream of the drainage area (Figure 3.93). Station 18 was about 710 m downstream from Station 17. Station 17 monitored water draining from the west prior to contributions from the drainage area. Station 18 remotely controlled Station 17, and the upstream station (Station 17) sampled water only when the downstream station (Station 18) was activated. Grab samples were also collected when Isco samples could not be obtained. For the purpose of comparing parameter concentrations between the two monitoring stations, and to determine field contributions to the drainage channel, samples collected using the same sampling method on the same dates from both stations were used for statistical analysis (Sub-section 2.8.4). A total of 35 snowmelt and 36 rainfall runoff pairings at Stations 17 and 18 were analyzed.

3.9.3. Results and Discussion

3.9.3.1 Soil

Agronomic samples. There was no consistent trend for extractable NO_3-N concentration with time among years (Table 3.67). However, on average, NO_3-N concentration in the spring was about twice the average concentration in the fall. This may in part reflect spring N fertilizer applications. The lower spring concentrations of NO_3-N in 2008, 2010, and 2011 may be due to leaching as these years had above average precipitation. Extractable NH_4-N concentration was generally less than 8 mg kg^{-1}, except in spring 2007 for the north field and in spring 2012 for both fields. Extractable NH_4-N concentration in spring 2012 was 10 to 13 times greater than the average of the other years. It is unknown what may have caused the very high NH_4-N concentration on both sides of the tributary in spring 2012. Overall, the average concentrations of NO_3-N and NH_4-N were similar in the drainage area on both sides of the tributary from 2009 to 2012. The highest concentration of NO_3-N and the second highest concentration of NH_4-N were measured on the north side of the tributary in spring 2007. These higher concentrations were likely caused by manure application in fall 2006.

Soil-test phosphorus concentration was highest in spring 2007 on the north side of the tributary at 112 mg kg^{-1} (Table 3.67), almost double the agronomic threshold of 60 mg kg^{-1} (Howard 2006). Similar to NO_3-N and NH_4-N in spring 2007, the high STP concentration was likely the result of manure application on north field in fall 2006. No additional manure was applied to the north side of the channel after 2006 and only a small amount of commercial P fertilizer was applied in 2010 and 2011 (Table 3.66). The average STP concentrations north of the tributary decreased with time following manure application in fall 2006. The STP concentration in the north field was considered high in terms of soil fertility for crop production (McKenzie and Middleton 2013); however, it was not excessive in terms of P accumulation from manure application. A manure application frequency of once every 3 to 4 yr likely prevented excessive P accumulation. The overall STP concentration at this site averaged 61 mg kg^{-1} among the 6 yr. The high concentration in spring 2007 was reduced in half within three crop years. On average from 2009 to 2012, STP concentration was about 36% less on the south side of the tributary compared to the north side. Perhaps, the south side of the tributary had not received as much manure in the past.

Table 3.67. Average (n = 9) nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) concentrations for agronomic soil samples collected from 2007 to 2012 at the South Manure Field.

	NO_3-N		NH_4-N		STP	
	Spring	Fall	Spring	Fall	Spring	Fall
Year	(mg kg^{-1})					
			North of tributary			
2007	61	21	15	5	112	65
2008	13	17	6	5	76	95
2009	49	11	5	4	64	75
2010	20	ns[z]	4	ns	58	ns
2011	6	18	3	3	40	51
2012	33	ns	53	ns	45	ns
			South of tributary[y]			
2009	36	9	7	5	29	33
2010	10	ns	5	ns	41	ns
2011	22	17	5	3	47	35
2012	44	ns	64	ns	31	ns

[z] ns = not sampled.
[y] The south side of the tributary was not sampled in 2007 and 2008.

Soil-test samples. The distribution of extractable NO_3-N, NH_4-N, and STP concentrations were similar with the highest concentrations in the 0- to 15-cm layer and then decreased with depth (Table 3.68). Nitrate N and NH_4-N concentrations were similar among the four quarter sections. Soil-test P concentration was highest in the NE quarter section (i.e., north of the tributary) compared to the other three quarter sections (i.e., mainly south of the tributary). This was similar to the agronomic soil sample results in terms of higher STP concentration north of the tributary, and as already suggested, this may be due to higher manure application rates and/or more frequent applications compared to the south side.

Soil-test samples were collected for the purpose of developing nutrient management plans for manure application as part of a BMP plan. However, due to climatic conditions and other unforeseen circumstances, manure was not applied as planned. Based on the results from the fall 2009 samples, the fertilizer recommendation for 2010 ranged from 15 to 146 kg ha^{-1} N and 0 to 4 kg ha^{-1} P (Table 3.68). The producer obtained independent nutrient recommendations for 2010 and applied 87 kg ha^{-1} N, 49 kg ha^{-1} K, and a small amount of P in the form of commercial fertilizers on both sides of the tributary (Table 3.66).

Table 3.68. Soil-test results for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for samples collected on October 22, 2009, and fertilizer recommendations for the 2010 crop year.

	Soil-test results			Fertilizer recommendations[z]	
Soil layer (cm)	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	STP (mg kg^{-1})	N (kg ha^{-1})	P (kg ha^{-1})
NW quarter section (feed barley south of tributary)					
0 to 15	10	5	32		
15 to 30	5	4	1	30	4
30 to 60	3	4	1		
SW quarter section (feed barley)					
0 to 15	10	5	45		
15 to 30	5	4	5	25	0
30 to 60	3	4	1		
NE quarter section (canola)					
0 to 15	10	5	61		
15 to 30	6	4	4	145	0
30 to 60	5	5	1		
SE quarter section (feed barley)					
0 to 15	14	6	26		
15 to 30	6	5	3	15	4
30 to 60	3	5	1		

[z] N and P recommendations were based on 0- to 60-cm soil-test results for NO_3-N, 0- to 15-cm soil-test results for STP, and wet spring soil moisture conditions.

Pre- and post-seeding samples. Extractable NO_3-N, NH_4-N, and STP concentrations on the north side of the tributary were slightly less in the post-seeding samples compared to the pre-seeding samples (Table 3.69). In contrast, the reverse was true on the south side of the tributary. However, the differences between the pre- and post-seeding averages were not statistically significant, suggesting that the added N (90 kg ha^{-1}) and P (20 kg ha^{-1}) fertilizer was not measurable in the soil. It is important to note the difference in seeding and fertilizing dates between the two sides of the tributary. Wheat was seeded north of the tributary on May 6, 2011, which was 1 d after the pre-seeding sampling and 54 d before post-seeding sampling. Canola was seeded south of the tributary on June 12, 2011, which was 38 d after the pre-seeding sampling and 17 d before post-seeding sampling. Above average precipitation occurred in May 2011 and June had near average precipitation (Table 3.2). These conditions may have caused NO_3-N to leach and/or denitrify on the north side from the time fertilizer was applied (May 6) until post-seeding sampling (June 29). Also, the wheat crop would have taken up some of the added N and P. The long-time span from fertilizer application to either the pre- or post-soil sampling was not ideal. The sampling dates were the result of not knowing exactly when seeding and fertilizing would occur and wet weather conditions.

3.9.3.2 Manure

Cattle manure samples collected in 2010 had an average water content of 2343 kg Mg^{-1} on a dry-weight basis, or 69% on a wet-weight basis. The average (n=12) nutrient concentrations were 3.90 kg Mg^{-1} NH_4-N, 20.4 kg Mg^{-1} TN, 5.25 kg Mg^{-1} TP, 15.3 kg Mg^{-1} TK, and 3.32 kg Mg^{-1} TS on a dry-weight basis. The TN concentration was within the range of values reported by Olson et al. (2003, 2010b) and Olson and Papworth (2006) for feedlot beef manure in southern Alberta; whereas, the NH_4-N concentration tended to be higher and the TP, TK, and TS concentrations tended to be lower than the previously reported values.

Table 3.69. Average (n = 9) nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) values for pre- and post-seeding soil samples collected at the South Manure Field in 2011.

	NO_3-N	NH_4-N	STP
	-----------------------------	(mg kg^{-1})	-----------------------------
		North of tributary	
Pre-seeding[z]	7*a*[y]	4*a*	44*a*
Post-seeding[x]	6*a*	3*a*	40*a*
		South of tributary	
Pre-seeding	8*a*	4*a*	37*a*
Post-seeding	22*a*	5*a*	47*a*

[z] pre-seeding samples collected May 5, 2011.
[y] Averages for each parameter for the north side and south side of the tributary followed by the same letter were not significantly different (P <0.1).
[x] post-seeding samples collected June 29, 2011.

3.9.3.3 Water Flow and Quality

Water flow. Both sides of the tributary contributed surface runoff with approximately one-third of the drainage area on the north side and two-thirds on the south side of the tributary (Figure 3.93). Field observations suggested that both sides contributed about equally to runoff. Runoff was observed draining into the tributary from both sides in late spring 2008, during snowmelt in 2009, and in late spring 2010 and 2011. Most of the flow through the tributary occurred from April to June in most years (Figure 3.96).

The annual flow was greatest in 2010 and 2011 compared to the other years (Figure 3.96, Table 3.70), and this was due to greater than average precipitation in these years (Sub-section 3.2). Of the total volume of water through the monitoring stations during the 6-yr period, more than 80% of the volume occurred in 2010 and 2011. Rainfall runoff was responsible for most of the flow at Stations 17 and 18 in most years, except in 2009 and 2012 (Table 3.70). On average among the years, 60 to 71% of the annual flow was from rainfall for the two stations. There was no base flow, i.e., groundwater discharge, observed in the tributary at this site.

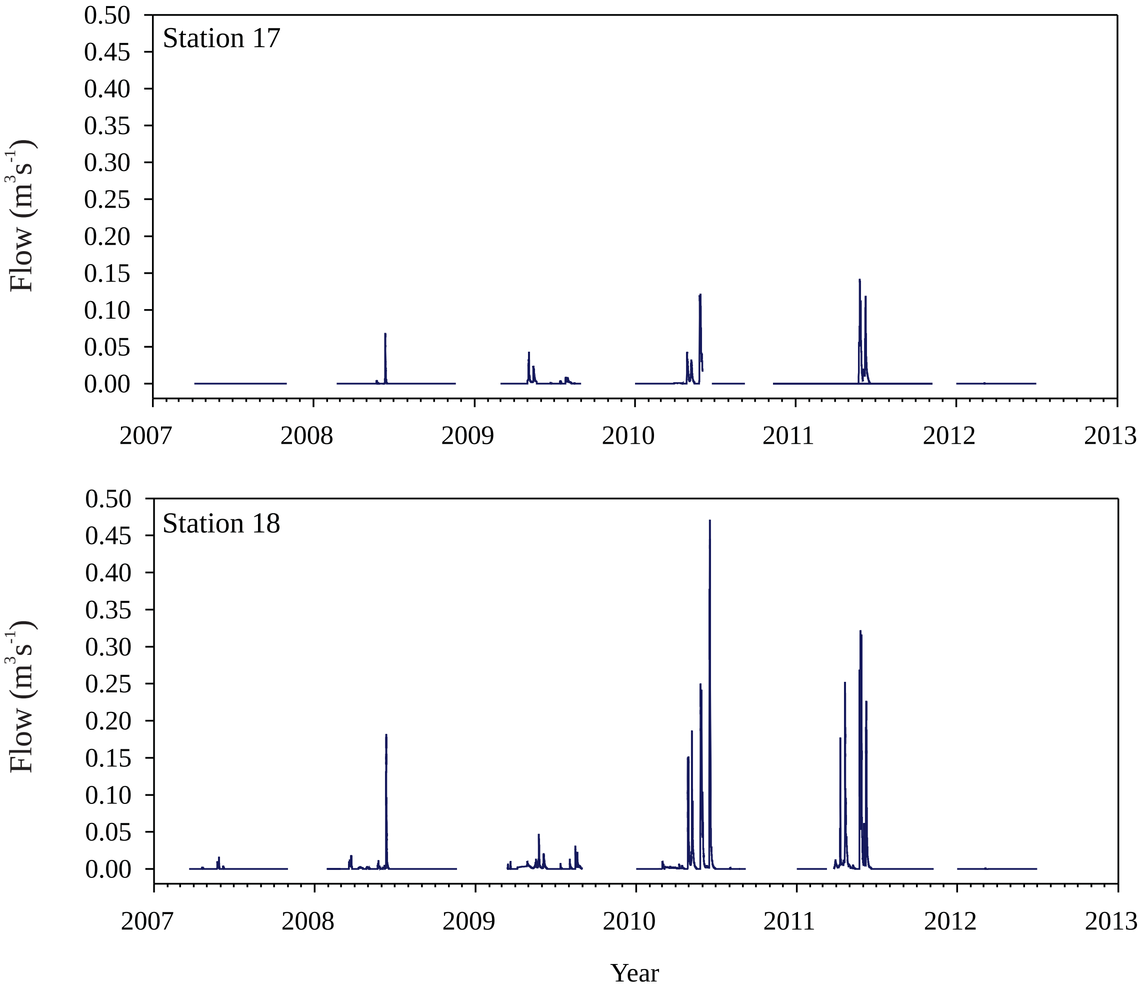

Figure 3.96. Annual hydrographs for Stations 17 and 18 at the South Manure Field from 2007 to 2012. Flow at Station 17 in 2007 was underestimated due the late installation of the instrumentation and water that bypassed under the flume.

Flow downstream at Station 18 was larger than at Station 17 each year. In the higher flow years (2008 to 2011), flows were 1.4- to 3.1-fold greater at the downstream station compared to the upstream station. However, flow was sometimes estimated for the stations during times of equipment failure. For example, at Station 17 the potentiometer float had a hole and was partially submerged in the stilling well of the circular flume after the large rainfall runoff event in early June 2010, the tributary and flume were buried in snow and ice during snowmelt in 2011 (Figure 3.97a), and water flowed around the flume at Station 18 during high flow in 2011 (Figure 3.97b). In spite of some difficulties in measuring flow during large events or freezing conditions, the data showed that the drainage area between the two monitoring stations contributed substantial runoff to the tributary. The area that drained to Station 17 was only slightly larger (74 ha) compared to the drainage area between Stations 17 and 18 (57 ha). It would appear that in most years, the latter drainage area contributed more to the tributary than the former drainage area, with 2009 being an exception (Table 3.70).

Table 3.70. Annual flow and proportions of flow attributed to snowmelt and rainfall runoff at the South Manure Field monitoring stations from 2007 to 2012.

	Station 17			Station 18		
Year	Flow (m^3 yr^{-1})	Proportion from snowmelt (%)	Proportion from rainfall (%)	Flow (m^3 yr^{-1})	Proportion from snowmelt (%)	Proportion from rainfall (%)
2007	6	na[z]	100	2,662	13	87
2008	8,861	0.3	99.7	27,341	20	80
2009	20,710	75	25	28,027	70	30
2010	61,104[y]	1	99	181,009	4	96
2011	77,270	na[x]	100	176,910	33	67
2012	78	100	0	518	100	0

[z] na = not available. Flow equipment was not installed until April, and therefore, snowmelt flows could not be determined in 2007.
[y] Flows were underestimated for Station 17 because the float potentiometer malfunctioned in June, 2010.
[x] No flow data were available for Station 17 during snowmelt in 2011 because the flume was buried in snow and ice and it was not possible to estimate flow.

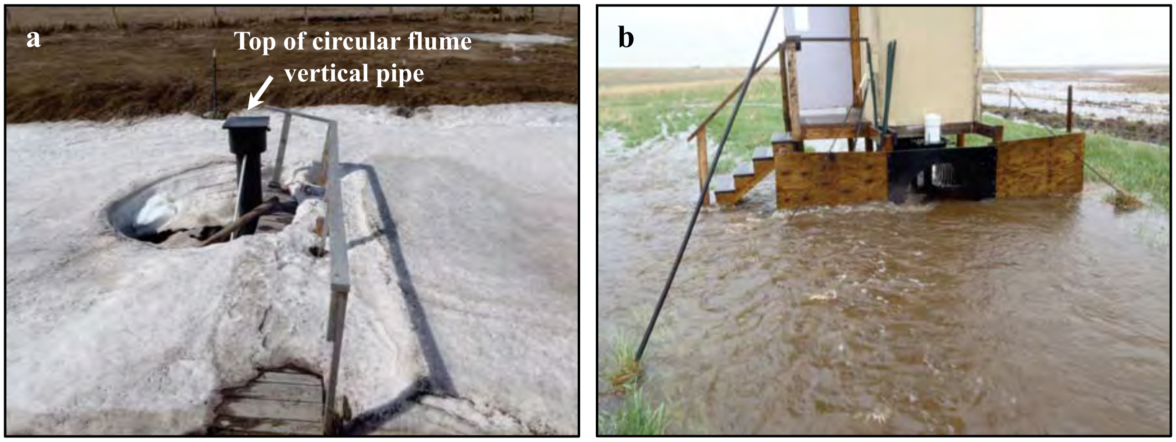

Figure 3.97. Images of (a) snow cover at Station 17 circular flume on April 26, 2011 and (b) high flow bypassing Station 18 on May 26, 2011.

Water quality. For most parameters in most years, concentration was higher during rainfall events compared to snowmelt events (Table 3.71). This was also mainly true for the overall averages among years, except for NH_3-N and EC at Station 17 (Table 3.72). One of the largest differences between event types was for *E. coli*. Average *E. coli* concentration was 30- to 41-fold greater during rainfall events compared to snowmelt events. This difference was likely the result of reduced bacteria activity during colder conditions of snowmelt. Another notable difference between the two event types was for NO_3-N at Station 18. Average NO_3-N concentration was four-fold greater during rainfall compared to snowmelt. This may suggest a higher risk of NO_3-N loss from the drainage area between the two monitoring stations during rainfall compared to other parameters.

Average TN and TP concentrations in rainfall events were greatest at both stations in 2009, 2010, and 2011 (Table 3.71; Figure 3.98a,b), which were also the years with the largest flows (Table 3.70). For snowmelt, TN concentration was greatest in 2012 followed by 2011 at both stations. Total P concentration at Station 18 was also greatest in 2012 followed by 2007; whereas, the greatest TP concentration at Station 17 was in 2011 followed by 2007. Higher concentration of water quality parameters were not necessarily always associated with high annual flows. In many cases, the two years (2007 and 2012) with the smallest annual flows had the largest concentrations compared to the other years. For example, for snowmelt flow at Station 18, the concentration of most parameters was the greatest in either 2007 or 2012. During rainfall events, the highest parameter concentrations, particularly for the N and P parameters, tended to be more consistently associated with the higher annual flows. However, no rainfall flow occurred in 2012.

Average TN consisted of 28% dissolved inorganic N at Station 17 and 44% dissolved inorganic N at Station 18 (Table 3.72). The majority of TP was in dissolved form, with 69% TDP at Station 17 and 84% TDP at Station 18. It would appear that as water moved from the upstream station (Station 17) to the downstream station (Station 18) the forms of N and P in water become more dominated by soluble forms. This may suggest that N and P in runoff from the drainage area in the adjacent fields were mainly in soluble forms. Another possibility is the change in channel characteristics from incised and little vegetation at Station 17 to shallow and grass cover at Station 18, may have influenced the change in the proportion of dissolved nutrients from upstream to downstream.

For all events, the average concentration of TDP significantly increased by 23% from upstream to downstream (Table 3.72). Average TN and NO_3-N concentrations also increased at the downstream station by 8 and 166%, respectively; however, they were not significantly different from the upstream station. The concentration of most of the remaining parameters decreased from upstream to downstream, with significant differences between the two stations for NH_3-N, PP, TSS, and *E. coli*. Total P concentration and pH were very similar between the two stations. Similar trends, for the most part, were observed in snowmelt and rainfall events (Table 3.72). One notable exception was that TN concentration decreased during snowmelt and increased during rainfall from upstream to downstream; however, the differences between the two stations were not significant.

Table 3.71. Average water quality parameter concentrations at Stations 17 (upstre am) and 18 (downstream) at the South Manure Field from 2007 to 2012.[z]

Year	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl[y]	*E. coli* (mpn 100 mL^{-1})	EC ($\mu S\ cm^{-1}$)	pH
	(mg L^{-1})											
						Station 17 - snowmelt						
2007 (3)[x]	5.11	3.58	0.45	0.99	1.46	1.14	0.32	41	na	314	294	7.60
2008 (7)	2.89	2.10	0.12	0.65	0.60	0.47	0.13	10	na	111	1053	7.44
2009 (10)	4.60	3.58	0.45	0.54	0.67	0.49	0.18	17[w]	13.3	522	2707	7.92
2010 (8)	4.47	2.95	0.04	1.46	1.11	0.78	0.33	28	9.30	853	616	7.41
2011 (5)	6.37	5.68	0.11	0.57	1.38	1.06	0.32	11	22.5	51	437	7.60
2012 (2)	12.2	2.39	9.13	0.57	1.19	0.93	0.26	41	14.0	2	738	7.48
						Station 18 - snowmelt						
2007 (3)	7.71	4.77	2.01	0.83	1.74	1.46	0.29	33	na	250	373	7.80
2008 (7)	2.16	2.09	0.03	0.03	0.88	0.85	0.03	2	na	19	337	7.79
2009 (10)	2.92	2.71	0.14	0.04	0.82	0.72	0.09	12[w]	10.4	97	529	7.93
2010 (8)	3.12	2.45	0.03	0.62	0.93	0.81	0.11	18	9.15	13	739	7.76
2011 (5)	5.10	3.65	1.07	0.34	0.77	0.68	0.09	3	22.3	3	776	7.65
2012 (2)	16.2	4.16	11.3	0.53	1.35	1.00	0.35	34	15.3	171	437	7.33
						Station 17 - rainfall[v]						
2007 (2)	4.92	3.34	1.44	0.12	0.32	0.12	0.21	42	na	3,030	1401	8.10
2008 (5)	5.26	3.73	1.08	0.35	0.63	0.31	0.32	55	na	28,114	537	7.96
2009 (6)	6.90	6.22	0.26	0.38	1.48	1.10	0.38	93	48.4	10,341	842	8.12
2010 (17)	8.51	6.30	1.47	0.60	1.52	0.93	0.59	63	32.2	10,788	581	8.02
2011 (6)	9.02	6.33	1.49	1.01	1.92	1.40	0.52	39	30.0	5,625	543	7.95
						Station 18 - rainfall[v]						
2007 (2)	5.21	3.79	1.34	0.07	1.44	1.37	0.07	4	na	820	1124	8.05
2008 (5)	5.01	4.12	0.79	0.08	1.16	1.09	0.07	9	na	2,393	513	7.84
2009 (6)	10.0	5.89	3.98	0.06	1.24	1.15	0.09	15	34.8	1,056	908	8.01
2010 (17)	9.23	4.76	3.98	0.40	1.44	1.10	0.34	31	24.9	2,366	621	8.04
2011 (6)	14.2	4.34	8.50	1.08	1.54	1.28	0.26	17	19.2	5,766	590	7.87

[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, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Chloride was added in late July 2008.
[x] Number of samples are shown in parenthes es.
[w] The TSS concentration values on April 8, 2009 were not included because the downstream concentration (1770 mg L^{-1}) was deemed to be an outlier value.
[v] No flow from rainfall runoff occurred in 2012.

Table 3.72. Upstream (Station 17) and downstream (Station 18) comparison of average water quality parameter concentrations at the South Manure Field from 2007 to 2012. [z]

Station	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl[y]	*E. coli* (mpn 100 mL^{-1})	EC (μS cm^{-1})	pH
	(mg L^{-1})											
	Snowmelt events (n =35)											
Upstream[x]	4.96	3.37	0.74	0.82*a*	0.96	0.71	0.24*a*	20*a*[w]	13.9	401*a*	1255	7.61*b*
Downstream	4.29	2.92	1.03	0.31*b*	0.96	0.84	0.12*b*	13*b*[w]	12.8	66*b*	555	7.78*a*
	Rainfall events (n = 36)											
Upstream	7.68	5.77*a*	1.22*b*	0.57*a*	1.39	0.91	0.48*a*	62*a*	35.1*a*	11,828*a*	658	8.02
Downstream	9.37	4.74*b*	4.14*a*	0.39*b*	1.38	1.15	0.24*b*	21*b*	25.8*b*	2,684*b*	676	7.98
	All events (n = 71)											
Upstream	6.34	4.59	0.98	0.69*a*	1.18	0.81*b*	0.37*a*	42*a*	25.3	6,195*a*	952	7.82
Downstream	6.87	3.84	2.61	0.35*b*	1.17	1.00*a*	0.18*b*	17*b*	19.8	1,375*b*	617	7.88

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Chloride was added in late July 2008.
[x] Averages with different letters per event and parameter indicate a significant difference between upstream and downstream at $P < 0.1$.
[w] The TSS concentration values on April 8, 2009 were not included in averages because the downstream concentration (1770 mg L^{-1}) was deemed to an outlier value.

As indicated above, overall average TP concentration was very similar at the two stations and this was also true for snowmelt and rainfall events. However, the relative proportions of TDP and PP changed between the stations. The concentration of TDP significantly increased by 23% from upstream to downstream; whereas, the opposite occurred for PP with a decrease of about 51% (Table 3.72). As TN concentration increased slightly from upstream to downstream, there was also a shift from particulate to dissolved N forms as water moved down the tributary. Average NO_3-N concentration was higher at the downstream station; whereas, ON concentration was reduced at the downstream station. The reduction of particulate forms of N and P was also reflected in TSS concentration, which decreased on average by about 60% from upstream to downstream. These results suggest that the runoff from the drainage area had a higher proportion of dissolved nutrients than in the water that entered the flume at Station 17. Zero tillage is extensively practiced in this watershed because of the high risk of soil wind erosion, and this practice may favour dissolved forms rather than particulate forms of nutrients in runoff. Any sediment that was exported from the field may have been trapped by the vegetative buffer zone along the tributary. As well, some of the sediment that entered this reach from upstream of Station 17 may have settled in the vegetative tributary.

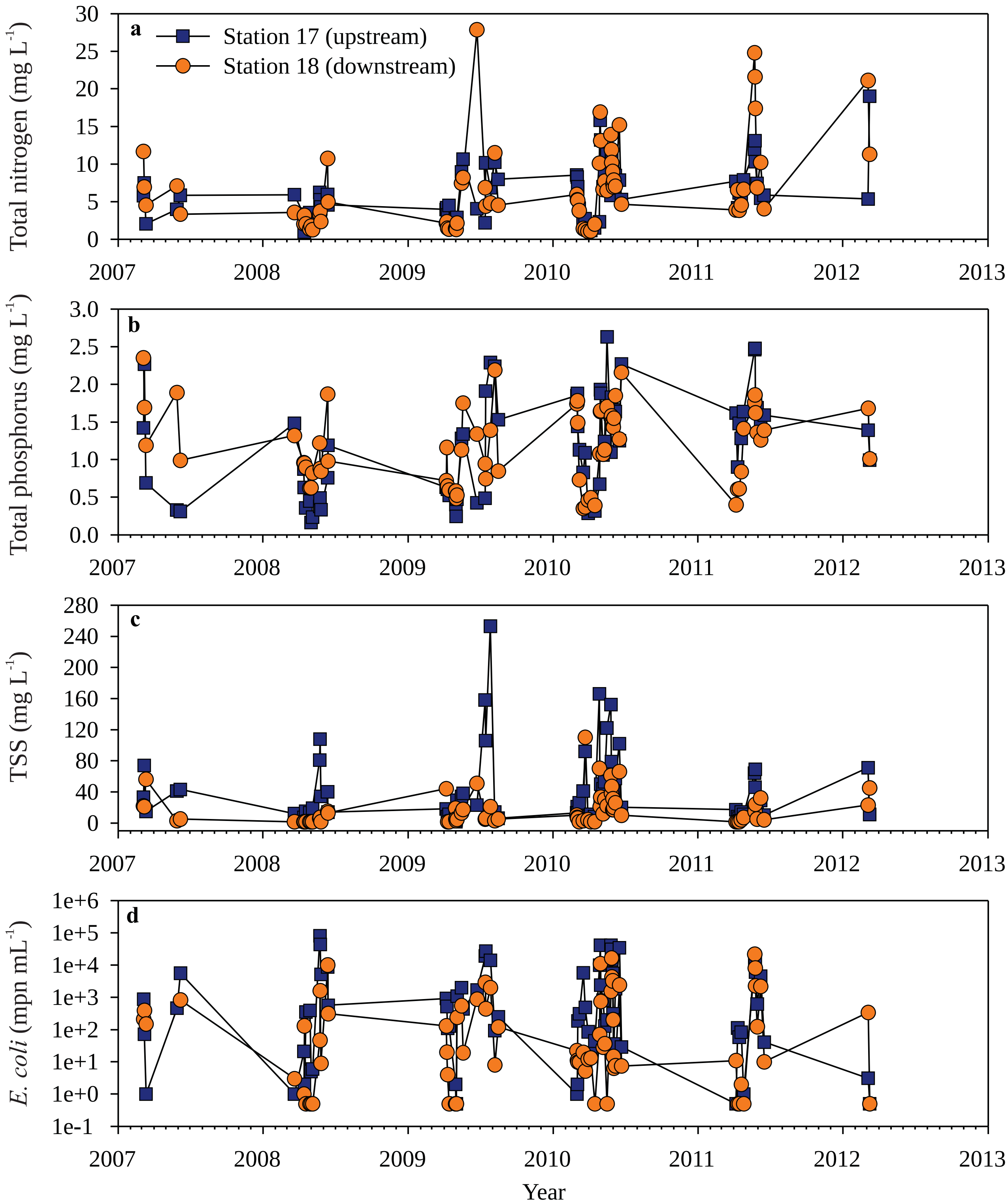

Figure 3.98. Concentrations of (a) total nitrogen, (b) total phosphorus, (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) at the South Manure Field from 2007 to 2012.

Cattle were often fall grazed at this site. Fall grazing in 2011 occurred on the north side of the drainage channel. A portable windbreak was placed a short distance from the tributary and Station 17 within the drainage area (Figure 3.95b). During the time cattle used the shelter, the bedding and accumulated manure at the windbreak was removed and piled nearby (Figure 3.95a). Also, a high density of fecal pats was created in the immediate area around the windbreak and adjacent to the tributary near Station 17 (Figure 3.99). In late fall 2011 and into 2012, extended field grazing was practiced by unrolling hay bales in swaths across the field (Figure 3.95a). The windbreak, bedding pile, and accumulated fecal pats were on land that sloped towards the tributary. No rainfall runoff flow occurred at the stations in 2012, and the average concentrations of TN, NO_3-N, and TSS in snowmelt were the highest in 2012 compared to the other years (Table 3.71). In addition, the largest increases in TN, ON, NO_3-N, PP, and *E. coli* concentrations from upstream to downstream were observed in 2012. This suggests that the bedding and feeding area and cattle activities in and around Station 17 in fall-winter 2011 and 2012 may have caused a negative impact on water quality in the tributary during spring 2012 snowmelt. If the practice of extended gazing at a wintering site continues, a suggested BMP would be to relocate the site further away from the tributary and in a location within the field that has a low risk of runoff entering the tributary. It should be noted that the annual flow in 2012 was smallest compared to the other years. The annual flow at Station 18 was 5- to 349-fold larger from 2007 to 2011 compared to 2012 (Table 3.70).

The significantly higher concentrations of PP, NH_3-N, TSS, and *E. coli* at Station 17 (upstream) (Table 3.72) were likely due to the presence of the cattle wintering and calving site upstream from Station 17 at the SMF site (Figures 3.93 and 3.100a). The tributary downstream from Station 17 was well vegetated, while the tributary upstream from Station 17 and into the wintering and calving pasture was not as well vegetated and was degraded by cattle access (Figure 3.101). The decrease in concentration from upstream to downstream suggest that sediment may have settled out and that there may have been little contribution from the fields in terms of these water quality parameters. However, actual field runoff was mixed with tributary water at this site. It was likely that the vegetation in and around the tributary may have improved water quality for some parameters. The size of the tributary and the grass area near the banks varied between Stations 17 and 18. The tributary was relatively narrow and deep near Station 17; whereas, it was relatively flat and undefined near Station 18 (Figure 3.100b,c). The banks near Station 17 were more disturbed as the agricultural field was almost at the edge of the tributary. In contrast, the grass banks extended

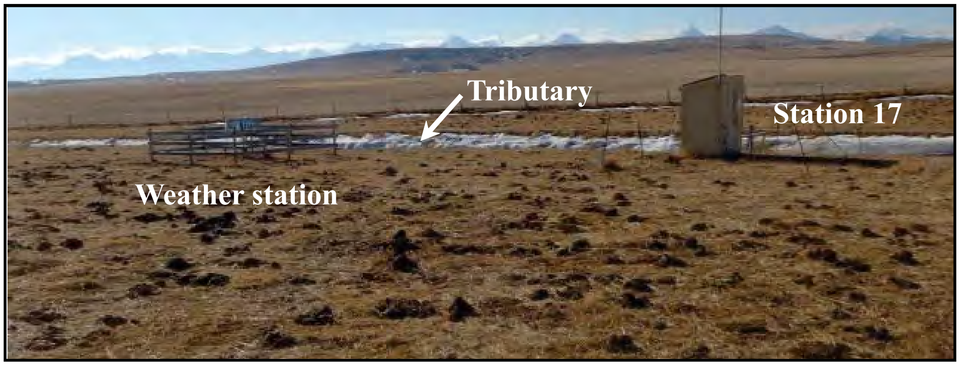

Figure 3.99. Accumulated fecal pats in close proximity to Station 17 and the tributary on February 9, 2012. The direction of flow in the tributary is from right to left.

10 to 20 m in some downstream locations. The vegetation likely acted as a filter for particulate material in areas where the bank had a wider buffer. It would appear that the cattle wintering and calving pasture upstream from the monitored site had a negative impact on the water quality in the tributary. A possible BMP would be to limit or prevent cattle access to the tributary in the pasture area.

Annual loads of all water quality parameters were much greater in 2010 and 2011 compared to the other years for both stations (Table 3.73). This was due to the much greater rainfall runoff flows in 2010 and 2011, as described previously. It was difficult to compare loads between the two stations because some flow data were missing for Station 17 in 2007, 2010, and 2011. In 2008, the loads for nearly all water quality parameters, except for PP and TSS, were greater at the downstream station. Even though the concentration of most parameters decreased from upstream to downstream in 2008 (Table 3.71), the annual flow increased by three-fold from upstream to downstream (Table 3.70) resulting in a net increase in parameter loads. In 2009, the flow increase from upstream to downstream was not as great and this resulted in TN, ON, NH_3-N, PP, and TSS loads smaller at the downstream station than at the upstream station because of decreased concentrations.

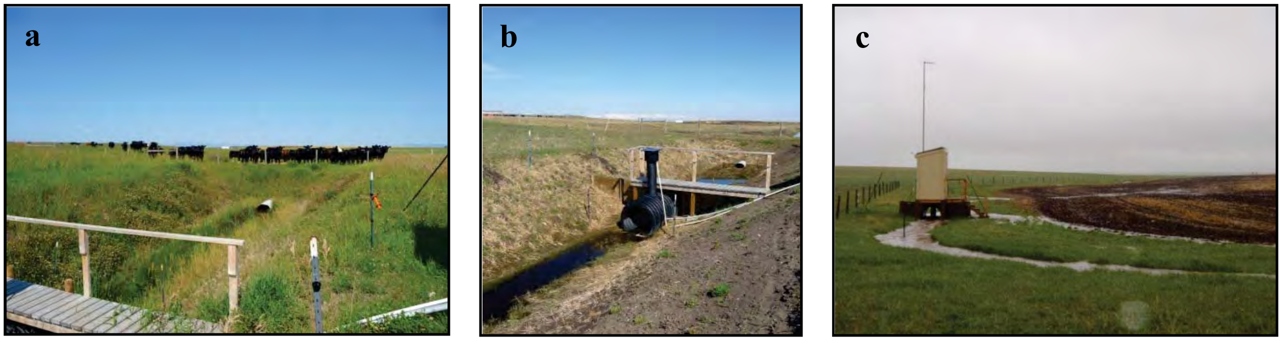

Figure 3.100. Images showing (a) cattle upstream from Station 17 on August 2, 2009, (b) deep channel and eroded banks at Station 17 on May 26, 2010, and (c) field runoff entering drainage channel upstream from Station 18 on May 27, 2010.

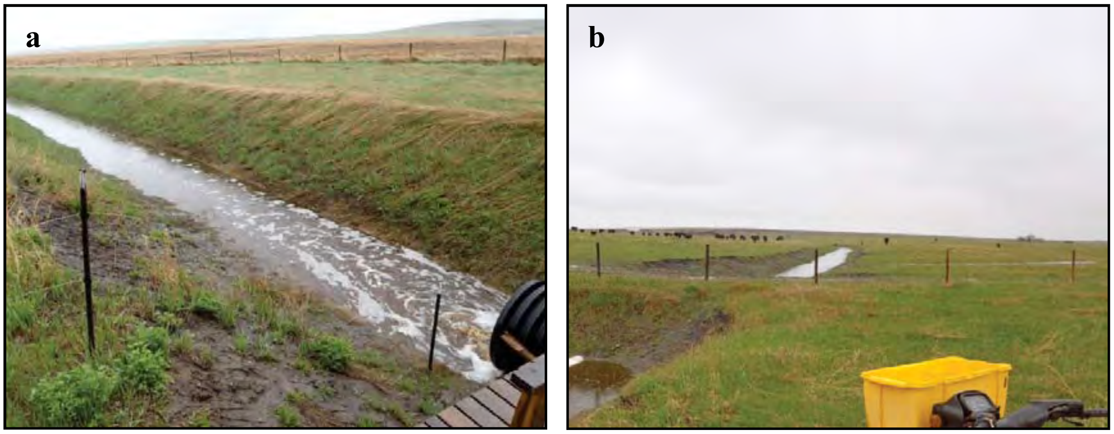

Figure 3.101. Tributary at the South Pasture Field (a) immediately downstream of Station 17 and (b) upstream of Station 17 into the cattle wintering and calving pasture to the west. Both images were taken on May 24, 2011.

Table 3.73. Annual water quality parameter loads in runoff at Stations 17 and 18 at the South Manure Field from 2007 to 2012.[z]

Station	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
	(kg)							
				2007				
17[y]	0.02	0.02	0.007	0.001	0.002	0.001	0.001	0.33
18	25.4	10.2	15.9	0.12	4.13	3.92	0.21	12.8
				2008				
17	47.7	41.3	3.55	2.62	7.76	4.76	2.99	324
18	208	175	26.0	3.55	40.6	38.9	1.74	317
				2009				
17	133	123	4.49	5.16	24.0	17.2	6.73	1224
18	128	110	15.9	1.41	28.1	25.0	3.10	432
				2010				
17[x]	593	406	129	46.4	95.3	66.3	29.0	3235
18	2008	758	1168	66.4	250	196	53.9	7498
				2011				
17[w]	607	437	86.6	72.5	131	98.0	32.9	2972
18	1941	731	1051	134	230	192	38.2	2895
				2012				
17	0.64	0.26	0.33	0.05	0.10	0.09	0.02	4.60
18	10.7	3.43	6.82	0.32	0.85	0.65	0.20	12.5

[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.
[y] Flow equipment was not installed until April, therefore, loads for 2007 are incomplete.
[x] Flows were underestimated for Station 17 because the float potentiometer malfunctioned in June 2010.
[w] No flow data were available for Station 17 during snowmelt in 2011.

3.9.4 Conclusions

- The implementation of BMPs at this site was not possible due to changing circumstances (e.g., no fall grazing in 2010) and unfavourable weather conditions (e.g., winter conditions prevent manure application in 2010). This site demonstrated that barriers and unforeseen circumstances may prevent the implementation of BMPs.

- Soil-test P concentration was not excessive at this site as a result of relatively infrequent (every 3 to 4 yr) manure application. The overall STP concentration was 61 mg kg^{-1} in the top 15 cm soil layer during the 6-yr period.

- A peak STP concentration of 112 mg kg^{-1} measured in 2007 was caused by manure applied in fall 2006. This peak concentration was reduced to less than the agronomic threshold (60 mg kg^{-1}) and demonstrated that a moderate amount of P accumulation can be managed within a relatively short period of time and likely minimize the risk to runoff water quality.

- Most of the flow through the tributary occurred from April to June in most years. Due to above average precipitation, the highest flow volumes occurred in 2010 and 2011. On average among the years, 60 to 71% of the annual flow at the two stations was from rainfall.

- Total N was mainly in ON form (56 to 72%) and TP was mainly in TDP form (69 to 84%) at both stations.

- The proportion of dissolved N and P fractions increased from upstream to downstream and may have been caused by a combination of the runoff from the field with relatively low amount of suspended solids and sedimentation within the vegetated tributary.

- Concentration for most water quality parameters was higher during rainfall events than during snowmelt events.

- Overall TDP and rainfall NO_3-N concentrations were significantly greater at the downstream station compared to the upstream station. This may be caused by runoff from the drainage area having a higher proportion of dissolved nutrients. Overall, NH_3-N, PP, TSS, and *E. coli* concentrations were significantly greater at the upstream station and this was likely due to cattle wintering and calving site upstream of Station 17. Limiting or preventing cattle access to the tributary in the pasture may improve water quality exiting the pasture area. The reductions in concentration of these parameters downstream may be caused by sedimentation in the tributary and limited contributions from edge-of-field runoff.

- The establishment of a winter bedding and feeding site upslope and a short distance from the tributary in fall 2011 had a negative effect on water quality in the tributary. A possible BMP would be to relocate the site further away from the tributary and in a location within the field that has a low risk of runoff entering the tributary.

3.10 Dairy Manure Field

3.10.1 Introduction and Hypotheses

The DMF was a relatively small site, i.e., less than a quarter section in size, and included a small dairy operation and farmland used for cereal and forage production. Liquid dairy manure was applied to the cereal land on a regular bases and the STP concentration was moderately high, about double the agronomic threshold of 60 mg kg^{-1} (Howard 2006). Manure was generally applied daily from September to May due to the lack of adequate storage.

Runoff from this site entered a road drainage ditch, which flowed into a nearby tributary of IFC. The loss of accumulated soil P to runoff water was the main concern at this site. The BMP plan focused on manure management and stopping manure application to allow the drawdown of STP. Runoff water quality and volume were monitored using a single edge-of-field station.

The underlying assumption was that the over-application of manure nutrients to the soil was contributing excessive nutrients in snowmelt and rainfall runoff at this site. The hypothesis was:

- The cessation of manure application will reduce STP and soil NO_3-N concentrations, and in turn, reduce dissolved P, dissolved N, and fecal bacteria in runoff.

Unfortunately, the BMP was implemented for only 1 yr, and as a result, the BMP could not be assessed at this site or test the hypothesis. To draw down STP levels, several years of crop removal and no P application are required. With only 1 yr of no manure application, the residual STP would continue to have an impact, and no improvement to water quality in runoff was expected. Similar to the SMF, which had a similar fate in terms of implementing BMPs, the monitoring data at DMF was used as an opportunity to study soil nutrients and runoff water quality at an agricultural field under specific management practices.

3.10.2 Methods

3.10.2.1 Site Description and General Management

The DMF was about 1 km south of Pincher Creek in the northwest part of the watershed (Figure 3.4). The DMF occupied an area of about 37 ha bordered by a road on the east side and a tributary of IFC on the west and north sides (Figure 3.102). The tributary flowed in a southwest to northeast direction. The dairy farmyard was in the southwest corner adjacent to the tributary. The dairy herd consisted of about 45 lactating cows. Surface runoff drained to the northeast through the DMF site. Starting at approximately the middle of the field, a vegetative drainage channel flowed north-northeast for about 270 m and into a dugout (19 by 62 m). When the dugout was full, water drained to the east for about 65 m and into a road ditch. Water in the ditch then drained north into the tributary. In addition to surface water contribution, water in the dugout was also influenced by a shallow groundwater table.

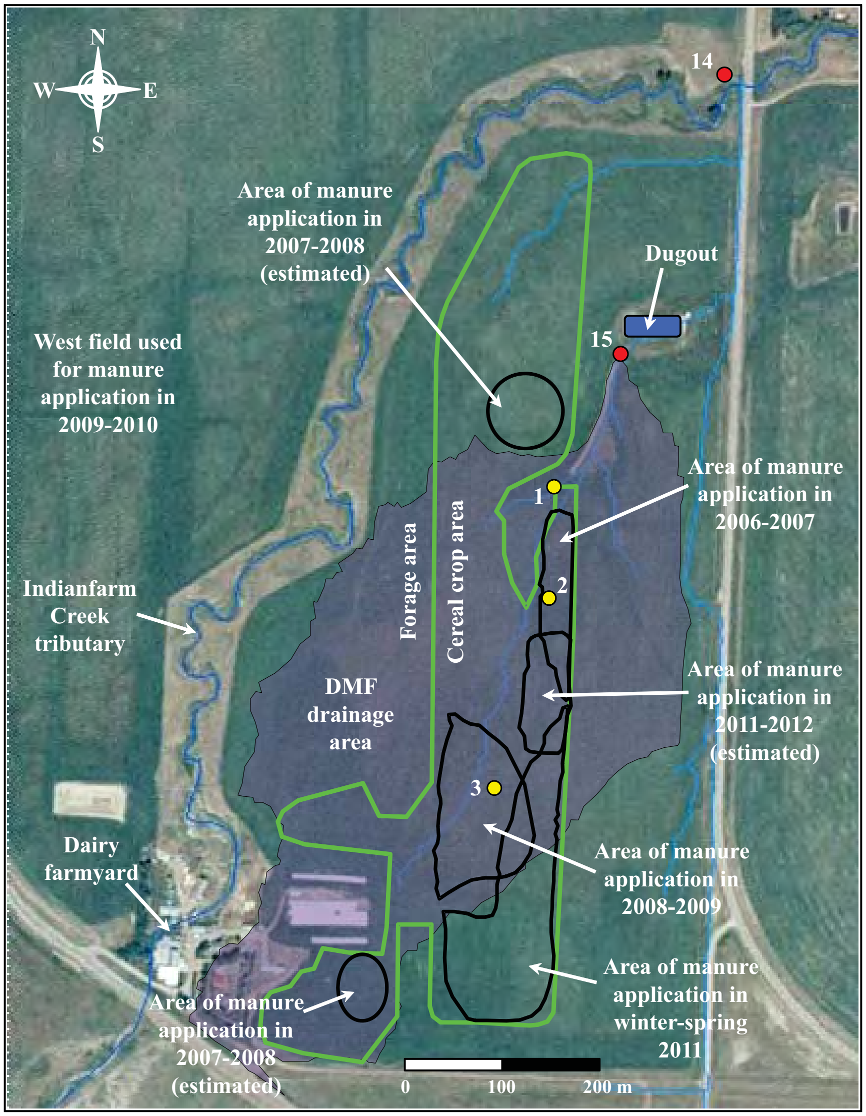

Figure 3.102. Dairy Manure Field (DMF) site showing annual crop and forage areas, manure application areas, and the three deep-core sample sites. The year ranges shown for the manured areas are from fall to the following spring.

Most of the DMF site was in the CWY1/U1h soil landscape model, as described in AGRASID (Alberta Soil Information Centre 2013). The soils in this model are Calcareous and Rego Black Chernozems, and includes dominant (60% or more) Cowley soil series and significant (10 to 30%) Cowley-ZR soil series, with well drained characteristics. The landform in the model is described as undulating, high relief with a limiting slope of 4%, and parent material consists of fine-textured, water-laid sediments with till-like features. The surface soil had a clay-loam texture (38% sand, 34 % clay), pH of 7.1, EC of 1.0 dS m^{-1}, 2900 mg kg^{-1} TN, 984 mg kg^{-1} TP, and 7% organic matter (Appendix 4).

Land use was annual cereal and alfalfa (Table 3.74) production. The barley field was in the centre of the field and was surrounded by alfalfa (Figure 3.102). At the end of the study, the barley field occupied an area of about 14 ha; however, at the start of the study the barley field was about twice this size. During the 6-yr study, a portion of the barley field (4 ha in 2008 and 8 ha in 2010) along the east side was converted to alfalfa. Commercial fertilizer N and P were applied to the barley portion of the field each spring. Barley was seeded in mid to late May. The alfalfa and barley crops were typically harvested in July and August, respectively.

Manure from the dairy herd was usually applied on a daily basis starting after harvest and continued until the following spring prior to seeding. Manure was applied on the cereal field portion of DMF site (Figure 3.102). Only a small portion (<2 ha) of the cereal field received manure each spreading season and the spreading area was moved from year to year. During the study, four areas of manure application were measured and they ranged in size from 0.4 to 1.9 ha (Figures 3.102 and 3.103). During the study period, manure was generally applied to the southern half of the cereal field. An open box spreader with a 7.6-m^3 capacity was used to apply the manure. The manure was allowed to pour from the back of the spreader as it was driven through the field. During the crop season, manure was composed. An exact application rate was not known, but assuming that one lactating cow produced 98.6 L d^{-1} of manure (AFRD 2006), 45 cows would have produced 4437 L d^{-1}. By assuming an application period of 240 days (i.e., September to May) and an application area of 1 ha, the application rate was estimated at 1,064,880 L ha^{-1} or 1065 Mg ha^{-1} (assuming manure density of 1 Mg m^{-3}), which is an extremely high rate. Even if the manure production was half this amount and the spreading area doubled, the application rate would still be high at 266 Mg ha^{-1}. In comparison, application rates for liquid manure typically range from 34 to 135 Mg ha^{-1} in the province (Trevor Wallace, Alberta Agriculture and Rural Development, 2014, personal communication). The number of animals used in this estimate may likely be low. In early 2008, the dairy had 43 lactating cows, 11 dry cows, and 22 heifers.

3.10.2.2 Implementation of Beneficial Management Practices

The BMP plan was to stop applying manure to the field because of the moderately high STP concentration. After 3 yr of pre-BMP monitoring (2007 to 2009) the BMP was implemented and no manure was applied from fall 2009 to spring 2010. The manure was applied on a different field located immediately on the west side of the tributary from fall 2009 to spring 2010 (Figure 3.102). The first year of post-BMP monitoring was 2010.

Unfortunately, after 1 yr of no manure application, the producer returned to the DMF site and applied dairy manure during the 2010-2011 and 2011-2012 seasons. This decision was made, in part, because wet conditions in fall 2010 made access to the field west of the tributary difficult. As was done in the past, manure was applied only to a small area in the DMF cereal field (Figure 3.102). With only 1 yr of BMP implementation at this site, the hypothesis could not be tested.

Table 3.74. Agronomic management practices at the Dairy Manure Field from 2007 to 2011.

Year	Crop	Seeding date	Harvest date	Yield (Mg ha^{-1})^{z}	Fertilizer N^{y} (kg ha^{-1})	Fertilizer P (kg ha^{-1})	Fertilizer K (kg ha^{-1})
2007	barley silage	May 25	Jul 22	na^{x}	73	-	-
	alfalfa buffer	-	late Jul	na	-	-	-
2008	barley silage	mid-May	mid-Jul	20	23	7	-
	alfalfa buffer	mid-May^{w}	mid-Jul	19	-	-	-
2009	barley silage	May 23	Aug 14	16	na	na	-
	barley grain	May 23	Aug 10	5.3	na	na	-
	alfalfa buffer	-	Jun 6	16	na	na	-
2010	barley silage	May 26	Aug 10	25^{w}	56	17	-
	barley grain	May 26	Sep 1	9.9^{w}	56	17	-
	alfalfa buffer	late May^{v}	Jul 19-22	22	-	-	-
2011	barley silage	May 26	Aug 15	9.0	67	22	6
	barley grain	May 26	na	na	67	22	6
	alfalfa buffer	-	Jul 28	20	-	-	-

[z] Silage yields express on a wet-weight basis.
[y] These nitrogen fertilizer application rates include broadcast N and N applied with the seed.
[x] na = N and P fertilizer was applied, but the rates were not available.
[w] Lower than anticipated yield due to hail damage on August 3, 2010.
[v] An additional 4 ha of alfalfa/triticale mix was seeded in May 2008 and 8 ha was seeded in May 2010.

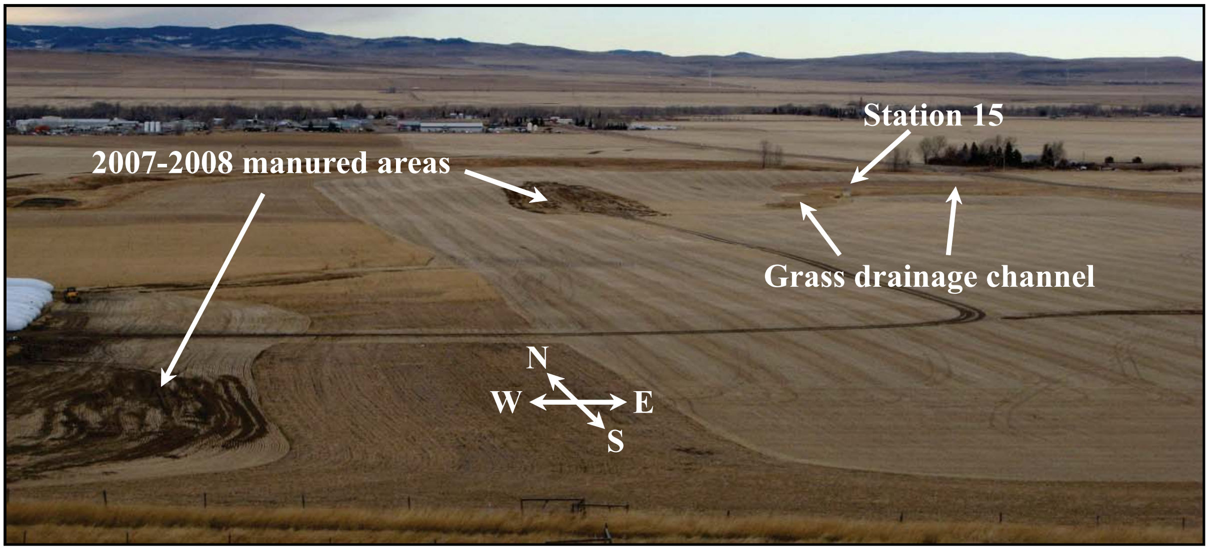

Figure 3.103. Manure application area on the Dairy Manure Field in 2007-2008.

3.10.2.3 Soil

Soil characterization samples (Sub-section 2.9) were collected on October 16, 2008. Agronomic samples (0 to 15 cm) were collected at this site annually from 2007 to 2012. The agronomic samples were collected on a 100- by 100-m grid, which was different from the 200- by 200-m grid used at other BMP sites. The smaller grid size was used at this site because manure was applied to only a small portion (about 1 ha) each year. The sampling grid covered the drainage area and some of the surrounding area (Figure 3.104).

Soil-test samples (0 to 60 cm) were collected in fall 2009 and 2010 (Sub-section 2.9). The DMF on the east side of the tributary was sampled in both years. The field on the west side of the tributary was sampled in fall 2009. The field on the west side of the tributary was used as an alternative field for manure application, when no manure was applied on the east side of the tributary in 2009-2010. In 2009, three transects were sampled on both sides of the tributary. In 2010, due to time constraints, soil-test samples were collected in conjunction with the agronomic samples using the 100-m grid. It was assumed that due to the relatively low topographic relief of the field, the grid sampling captured variations within the field and provided representative samples comparable to the transect method.

Three deep core samples (0 to 300 cm) were collected within the cereal field in October 2009. Deep Core 1 was sampled in an area where manure had not been recently applied and Deep Cores 2 and 3 were sampled where manure was applied in 2007-2008 and 2008-2009, respectively (Figure 3.102).

3.10.2.4 Manure Sampling

Manure samples were collected 20 times, once every 2 to 3 wk from March 2008 to February 2009. Manure was generally removed from the dairy barn on a daily basis using a manure box spreader. During each sampling, a 1-L sample was removed from the manure spreader prior to disposal of the manure. Samples were analyzed for water and nutrient content (Sub-section 2.10).

3.10.2.5 Water Flow and Quality

This site was equipped with a single edge-of-field monitoring station (Station 15), which included a circular flume and automatic Isco water sampler (Sub-sections 2.6, 2.7, and 2.8). Snowmelt and rainfall runoff water samples were collected from 2007 to 2012. The water samples were analyzed for nutrients, TSS, and *E. coli* (Sub-section 2.8). A total of 16 snowmelt and 25 rainfall runoff samples were collected and analyzed from this site. The flow equipment was not operational until the spring 2007, and as result, no flow data were collected for the snowmelt sample collected on March 6, 2007.

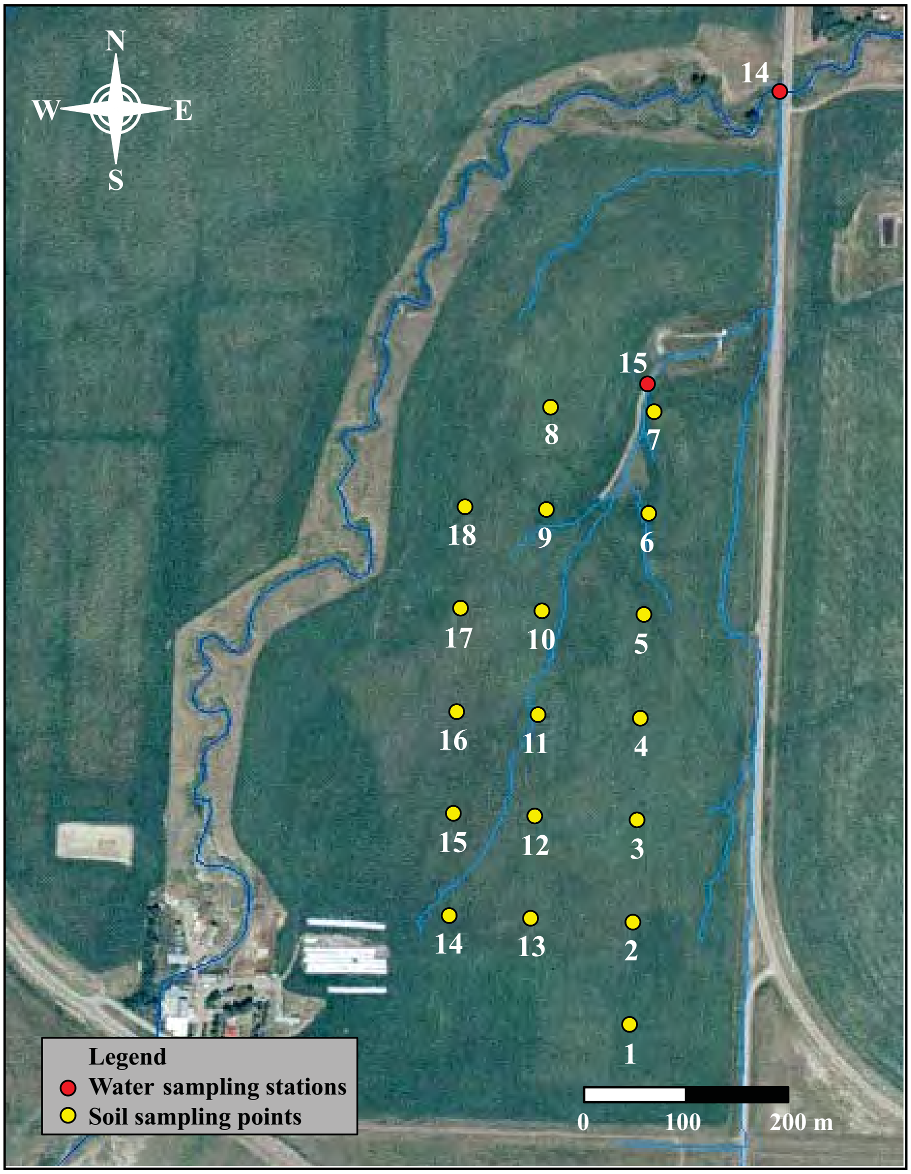

Figure 3.104. Agronomic soil (0 to 15 cm) sampling points at the Dairy Manure Field.

3.10.3 Results and Discussion

3.10.3.1 Implementation of Beneficial Management Practices

As indicated previously, the BMP implementation was not successful and could not be evaluated in terms of water quality. The BMP plan was to stop manure application at the DMF to allow the moderately high STP concentration to decrease with crop removal to a level at or less than the agronomic threshold. A nutrient management plan involving soil sampling would have been used to monitor STP and determine if commercial N fertilizer was required.

The BMP was only implemented for 1 yr, and several years would have been required to reduce the STP concentration. Once the STP concentration was reduced to a desirable level, the resumption to manure application based on the crop removal of P would have been considered a long-term BMP to prevent STP from re-accumulating. The lack of adequate storage required that manure be applied daily from September to May season, which often meant the application of manure on snow-covered and/or frozen soil. Winter application is not considered a good practice. Adequate storage would be required in order to prevent winter application of manure at this site. However, constructing a liquid manure storage facility was beyond the capacity of this study.

3.10.3.2 Manure

The dairy manure applied on the field was considered semi-solid manure with an average water content of 5320 kg Mg^{-1} on a dry-eight basis, or 83% on a wet-weight basis. The average nutrient concentrations were 15.8 kg Mg^{-1} NH_4-N, 25.5 kg Mg^{-1} TN, 6.75 kg Mg^{-1} TP, 21.0 kg Mg^{-1} TK, and 5.09 kg Mg^{-1} TS on a dry-weight basis (Table 3.75). During the 12 mo of sampling in 2008 and 2009, the concentrations of NH_4-N, TN, and TK decreased with time; whereas, TP and TS concentrations were generally consistent with time (Figure 3.105). Ammonium N and TK concentrations were more variable compared to the other three nutrients. The average TP content of semi-solid dairy manure from the DMF site (6.75 kg Mg^{-1}) was greater than solid beef manure (5.41 kg Mg^{-1}; n = 40) but less than liquid dairy manure measured at other BMP sites in the project (9.90 kg Mg^{-1}; n = 34).

Table 3.75. Average (n = 20) nutrient content of manure at the Dairy Manure Field from 2008 to 2009, estimated applied nutrient load, and typical crop removal rate of nutrients.

	NH_4-N	Total N	Total P	Total K	Total S
Nutrient content of manure (kg Mg^{-1})[z]	15.8	25.5	6.75	21.0	5.09
Nutrient load applied (kg ha^{-1})[y]	2861	4617	1222	3802	922
Nutrient removed by crop (kg ha^{-1} yr^{-1})[x]	-	122	18	80	14

[z] Expressed on a dry-weight basis. Average water content was 5320 kg Mg^{-1} on a dry-weight basis, or 83% on a wet-weight basis.
[y] Assumed manure application rate of 1065 Mg ha^{-1} (wet weight) based on: 45 dairy cows produced 98.6 L d^{-1} of manure (AFRD 2006) for a total of 4437 L d^{-1}, manure was produced for 240 d from September to May and applied to 1 ha of land, and density of manure was 1 Mg m^{-3}.
[x] Based on barley silage yield of 20 Mg ha^{-1} at 65% water content and nutrient removal values from Canadian Fertilizer Institute (2001).

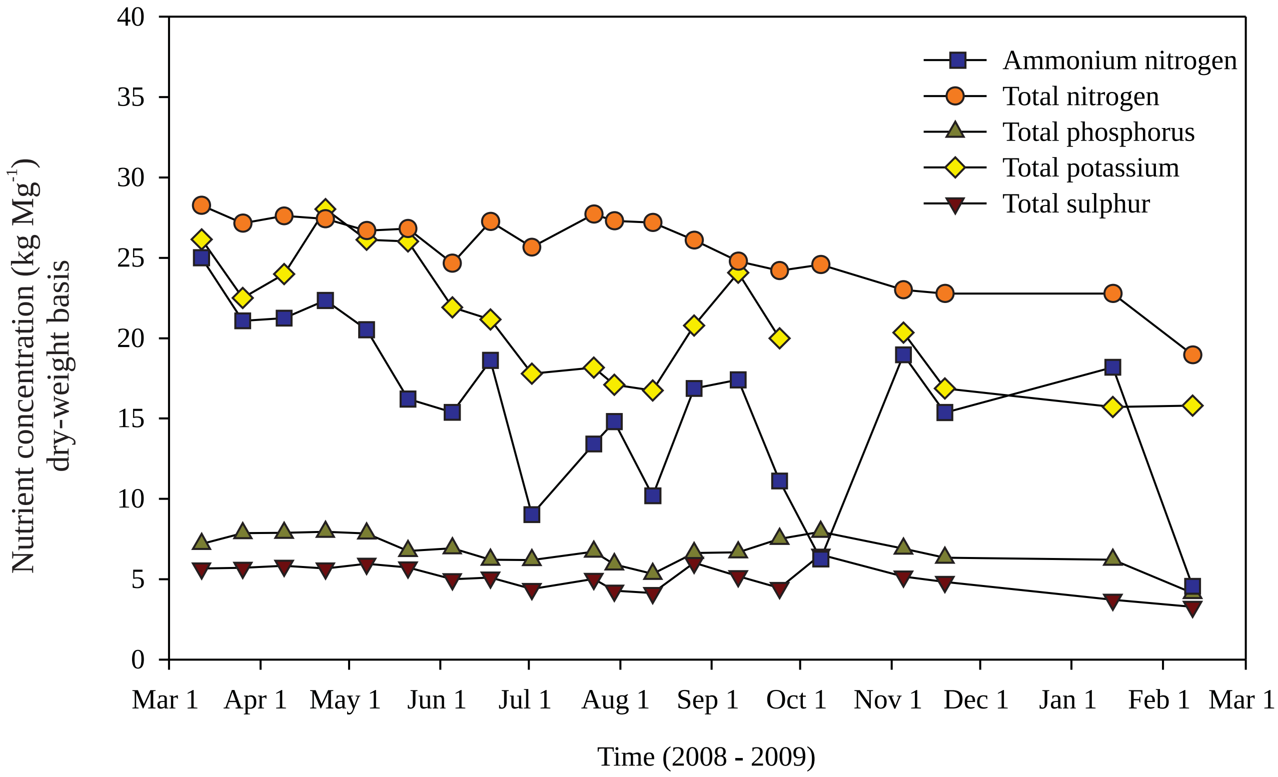

Figure 3.105. Manure nutrient concentrations from March 2008 to February 2009 at the Dairy Manure Field.

Based on the average water and nutrient content of the manure sampled in 2008 and 2009 and an application rate of 1065 Mg ha^{-1}, it was estimated that the average annual nutrient load applied was very high compared to what a silage barley crop may typically remove in a single growing season (Table 3.75). These estimates showed that the nutrient load applied was likely 38 to 68 times greater than crop removal in a single growing season.

However, this can be taken a step further since the area that received manure in a given year was only a small portion (0.4 to 1.9 ha) of the field and may not receive manure again until several years later. At the end of the study, the cereal crop area at the DMF site was about 14 ha in size. If the area of manure application was carefully managed to avoid overlap from year to year, it would take about 14 yr to cover the whole field with manure, assuming an average application area of 1 ha yr^{-1}. Therefore, the estimated manure application rate of 1065 Mg ha^{-1} could be considered a 1-in-14 yr application. For TN, this would represent 330 kg ha^{-1} yr^{-1} for a 14-yr period. Approximately 62% of the TN was in NH_4-N form (Table 3.75). Manure application was surface applied without incorporation. The lack of immediate incorporation of manure can lead to loss of NH_4 by volatilization as ammonia (NH_3). McGinn and Sommer (2007) reported 40 to 48% of total NH_3 in surface-applied, non-incorporated beef manure was volatilized within 6 d of application in southern Alberta. They also observed that the highest losses of NH_3 occurred within the first few hours of application. In addition to volatilization, denitrification may also contribute to gaseous loss of N, particularly during wet soil conditions. If we assume that about 50% of the TN was lost through gaseous forms, then this would reduce the TN remaining from manure to 165 kg ha^{-1} yr^{-1} during the 14-yr period. Furthermore, not all of the TN remaining in the soil would be mineralized and available for crop use. Therefore, the amount of net N applied to the soil may not be in excess of the amount of N removed by the crop (estimated at 122 kg ha^{-1} yr^{-1}). However, crop removal of N would occur during the course of several years; whereas, the N load is applied at one time and unused N would be subject to loss.

Phosphorus from manure is not subject to gaseous losses and tends to remain in surface soils. The amount of TP applied in a single, 1-in-14 yr application would represent 87 kg ha^{-1} yr^{-1} TP. This amount was nearly five-fold greater than the estimated amount removed annually by a silage barley crop (Table 3.75). Therefore, P accumulation would be expected in the soil at the DMF site.

3.10.3.3 Soil

Agronomic samples. Extractable NO_3-N, NH_4-N, and STP concentrations showed no consistent trends with time or between spring and fall sampling (Table 3.76). Nitrate N concentration was the lowest in 2010 and this was likely caused by greater leaching as a result of higher than average precipitation in 2010 (Sub-section 3.2). Nitrate N is mobile in the soil and susceptible to leaching (Olson et al. 2009). The concentration of NO_3-N ranged from 1 to 145 mg kg^{-1} among all sample points and seasons. The high variability of NO_3-N concentration is likely related to the inherent variability caused by years of manure applications and the method of application used at this site.

Soil-test P concentration fluctuated during the study, with an overall average of 126 mg kg^{-1}, which was about double the agronomic threshold of 60 mg kg^{-1}. Measured STP concentration ranged from 10 to 606 mg kg^{-1} among all sample points and seasons. Similar to NO_3-N, the high variability of STP was likely due to manure application, particular in terms on manure distribution method and high application rate.

Table 3.76. Average nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) concentrations for the agronomic soil samples (0 to 15 cm) collected from 2007 to 2012 at the Dairy Manure Field.

	NO_3-N		NH_4-N		STP	
	Spring	Fall	Spring	Fall	Spring	Fall
Year	(mg kg^{-1})					
2007	36	21	13	6	113	105
2008	27	25	7	5	116	157
2009	17	18	5	6	96	138
2010	9	5	5	5	184	137
2011	12	21	5	6	110	133
2012	37	-	12	-	98	-

Soil-test samples. The soil-test sample results were similar for the DMF between 2009 and 2010 (Table 3.77). The field west of the tributary had noticeably lower STP values in the 0- to 15-cm layer compared to the DMF. This suggests that less manure may have been applied to the west field in the past. The 2009 and 2010 STP concentrations at DMF in the 0- to 15-cm soil-test samples (80 and 83 mg kg^{-1}, respectively) were less than the agronomic sample averages in fall 2009 and 2010 (138 and 137 mg kg^{-1}), further illustrating the STP variability within this field (Table 3.77).

The 2009 soil-test results were used to development nutrient management plans for the 2010 crop year for the DMF and the west field. Manure was not applied in 2009-2010 to DMF and was instead applied to the west field. Fertilizer recommendations, based on the soil-test results and the AFFIRM program (AFRD 2005), were 56 kg ha^{-1} N for DMF and 73 kg ha^{-1} N for the west field. No fertilizer P was recommended for either field in 2010. The recommended rate for N was followed for the DMF site in 2010; however, 17 kg ha^{-1} P was also applied (Table 3.74). This amount of added P was about the same as the estimated P removed by a crop of barley (Table 3.75). Therefore, no net reduction in soil P would have been expected after the 2010 crop season. This was also likely the case for 2011, when 22 kg ha^{-1} P was applied to the DMF site (Table 3.74). To achieve the long-term BMP goal of reducing soil P content at the DMF site, no P of any form should be applied to the field.

Deep-core samples. Extractable NH_4-N concentration was similar among the three cores and changed very little with depth (Table 3.78). The concentrations of NO_3-N, STP, and Cl were higher in Deep Cores 2 and 3 compared to Deep Core 1. Deep Core 1 was sampled in an area that had not received manure for at least 4 yr; whereas, Deep Core 2 was sampled less than 3 yr after manure application and Deep Core 3 was sampled approximately 8 mo after manure application. The higher nutrient concentrations in Cores 2 and 3 were likely due to the more recent manure applications, which were estimated to have been at very high rates.

The NO_3-N concentration in the 0- to 60-cm layer (Table 3.78) was estimated to be equivalent to about 320 kg ha^{-1} NO_3-N for Deep Core 2 and about 275 kg ha^{-1} NO_3-N for Deep Core 3. Both of these values were greater than the NO_3-N limit of 225 kg ha^{-1} in AOPA for a medium to fine textured soil in the Black Soil Zone (Province of Alberta 2010). As well, the NO_3-N concentration was in excess of crop requirements and no fertilizer N would have been required based on AFFIRM. Deep Cores 2 and 3 had higher surface NO_3-N concentrations than the agronomic and soil-test samples. These two cores were specifically targeted in areas of recent manure application;

Table 3.77. Soil-test results for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for samples collected at the Dairy Manure Field (DMF) in 2009 and 2010 and from the field on the west side of the tributary (west field) in 2009.

	2009 - DMF			2009 - west field			2010 - DMF		
Soil layer	NO_3-N	NH_4-N	STP	NO_3-N	NH_4-N	STP	NO_3-N	NH_4-N	STP
(cm)	(mg kg^{-1})								
0 to 15	12	4	80	7	5	61	6	4	83
15 to 30	5	4	6	4	5	3	4	2	4
30 to 60	3	3	1	2	4	1	5	2	1

whereas, the agronomic and soil-test samples were collected using field-wide sampling. These results again show the nutrient variability in this field. Soil-test P concentrations were more than double the agronomic threshold of 60 mg kg^{-1} in Deep Cores 2 and 3 (Table 3.78).

Table 3.78. Nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), soil-test phosphorus (STP), and chloride (Cl) concentrations in three deep cores sampled (Figure 3.102) at the Dairy Manure Field in October 2009.

Soil layer (cm)	NO_3-N	NH_4-N	STP	Cl
	(mg kg^{-1})			
		Deep Core-1		
0-30	8	4	58	7
30-60	5	3	8	3
60-90	5	2	4	3
90-120	5	2	1	4
120-150	5	2	1	8
150-180	5	3	1	11
180-210	7	3	1	10
210-240	6	3	1	10
240-270	6	3	1	11
270-300	6	3	1	12
		Deep Core-2		
0-30	53	4	151	32
30-60	27	3	1	46
60-90	25	3	1	188
90-120	16	2	1	114
120-150	9	2	1	45
150-180	6	1	1	14
180-210	12	2	1	34
210-240	11	2	1	32
240-270	7	1	1	20
270-300	7	1	1	23
		Deep Core-3		
0-30	56	6	133	40
30-60	13	3	1	14
60-90	6	3	1	11
90-120	4	3	1	49
120-150	5	5	1	36
150-180	6	7	1	16
180-210	5	5	1	9
210-240	5	4	1	6
240-270	4	4	1	5
270-300	4	4	1	6

Even though the Deep Core 2 area received manure about 2 yr prior to the Deep Core 3 area, average NO_3-N concentration in the profile was about 70% higher and Cl concentration was more than doubled in Deep Core 2 compared to Deep Core 3. Possibly, the Deep Core 2 area received a higher rate of manure than the area where Deep Core 3 was sampled. The concentrations of NO_3-N and Cl were higher at deeper depths in Deep Core 2, suggesting that the longer time between manure application and soil sampling allowed leaching of soluble constituents to greater depths compared to Deep Core 3.

It is unknown when manure was last applied to the area where Deep Core 1 was collected, but manure had not been applied for four or more years prior to soil sampling. The concentration of STP in the surface soil layer was near the agronomic value of 60 mg kg^{-1} (Table 3.78). However, this value is for a 30-cm layer and the STP concentration was likely much higher in the top 15 cm, as added P tends to stratify and accumulate near the soil surface (Olson et al. 2010a,b). However, compared to the STP concentrations in the surface soil for the other two deep cores, the lower STP concentration in Deep Core 1 may demonstrate possible reduction in STP with no manure application for several years. The slightly higher STP concentration in the 30- to 90-cm layer of Deep Core 1 suggests that some of the long-term residual P may have leached into lower depths. As well, the slightly higher Cl concentrations in the lower portion of Deep Core 1 may be the remaining residual Cl from manure applied several years prior.

The deep-core results suggest that this site was prone to NO_3-N leaching and that the risk of leaching increased with manure application. This was not the case for P, which is relatively immobile in soil and does not readily leach. The increased risk of NO_3-N leaching is affected by landscape and management factors. Soil at this site is fine textured and is subject to deep cracking when dry. These cracks can act as conduits for preferential flow and the movement of soluble material into the soil profile. Since the water table at this site is relatively shallow, there is also the risk of NO_3-N leaching into shallow groundwater. This risk is compounded by the fact that manure is generally applied to a small area at this site in a given year and at very high rates. Applying the manure on a larger area would allow crops to utilize more of the N before much of it is potentially leached below the root zone.

3.10.3.4 Water Flow and Quality

Water flow. The majority of flow at this site occurred within the March to June period in most years (Figure 3.106). Some runoff flow did occur in July 2008 and 2010, August 2010, and October 2011. During 2008, all flow at this site was caused by snowmelt, while in 2010 rainfall was responsible for all the flow. Flow during the remaining 4 yr was a combination of snowmelt and rainfall runoff (Table 3.79). On average during the 6-yr study, 39% of flow was caused by snowmelt and 61% of the flow was caused by rainfall. However, all flow in 2008 and a majority of flow in 2009 were caused by snowmelt. The annual flow in 2011 was much greater compared to the other years (Figure 3.106), with a value almost five-fold more than the 6-yr average (4185 m^3 yr^{-1}). This was the result of above average precipitation in 2010 and 2011. The above average precipitation in 2010, likely resulted in high antecedent soil moisture in 2011 and more groundwater discharge in the area due to a higher water table. The hydrograph for 2011 shows a tailing out of the flow, suggesting possible influence of groundwater discharge in the drainage channel upstream from the monitoring station.

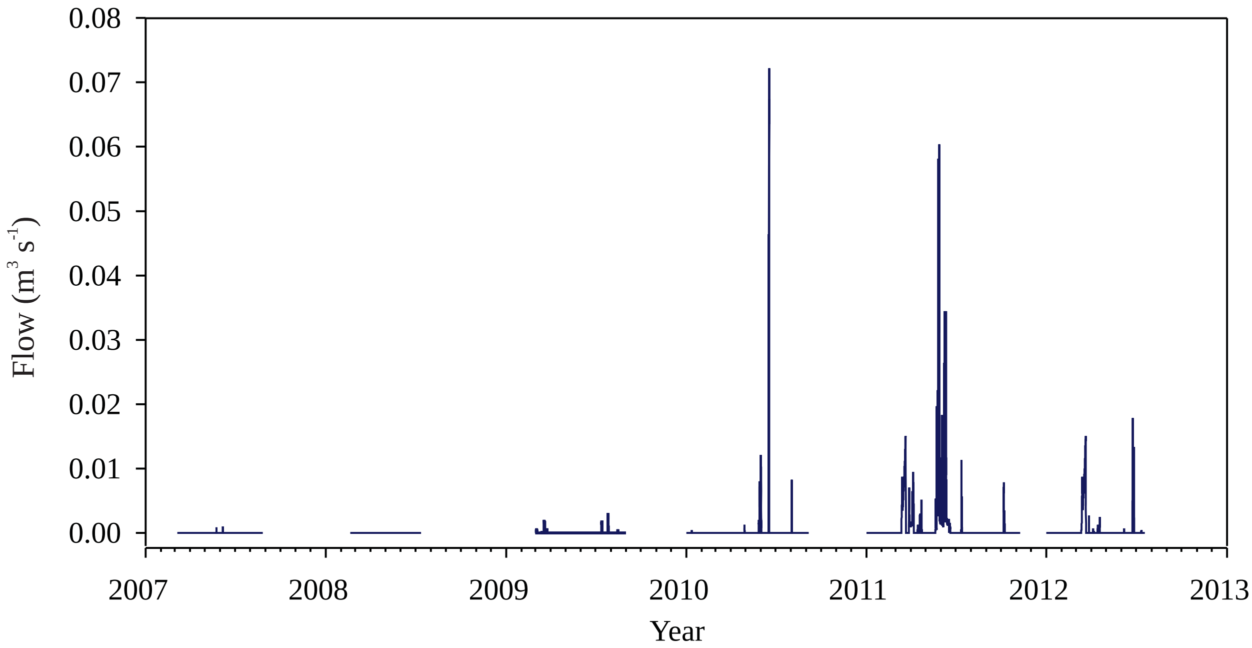

Figure 3.106. Annual hydrographs for Station 15 at the Dairy Manure Field from 2007 to 2012.

Table 3.79. Annual flow and proportions of flow attributed to snowmelt and rainfall runoff at the Dairy Manure Field from 2007 to 2012.

Year	Flow (m^3 yr^{-1})	Proportion from snowmelt (%)	Proportion from rainfall (%)
2007	21[z]	na[y]	<100
2008	15	100	0
2009	297	72	28
2010	3,312	0	100
2011	20,331	43	57
2012	1,136	17	83

[z] This value does not include snowmelt because the flow equipment was not operational until spring 2007.
[y] na = not available.

Water quality. Overall, the average concentration of most water quality parameters was higher during rainfall runoff compared to snowmelt runoff (Table 3.80). The higher concentrations in rainfall runoff compared to snowmelt ranged from 10% higher for ON to more than three-fold higher for NO_3-N (Table 3.80). The higher concentration of *E. coli* in rainfall runoff was likely the result of warmer temperatures allowing for increased microbial activity. In contrast, average NH_3-N and PP concentrations in rainfall runoff were 76% and 16% lower, respectively, compared to snowmelt runoff. The average pH values were similar between the two events types.

Table 3.80. Average runoff water quality parameters measured at Station 4 at the Dairy Manure Field from 2007 to 2012.[z]

Year[y]	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli*	EC	pH
		----------	----------	----------	----------	(mg L^{-1})	----------	----------	----------	----------	(mpn 100 mL^{-1})	(µS cm^{-1})	
							Snowmelt						
2007	1	6.20	4.23	1.67	0.27	1.47	0.44	1.03	37	na[x]	5	643	8.20
2008	1	2.20	1.37	0.37	0.43	0.64	0.61	0.03	32	na	1	223	7.70
2009	3	5.58	3.05	1.71	0.75	0.92	0.62	0.30	111	11.2	1	300	8.07
2011	8	12.9	4.92	5.97	1.81	2.85	2.63	0.22	12	62.0	467	974	7.99
2012	3	3.10	2.44	0.44	0.20	1.03	0.61	0.42	41	63.8	2	964	8.12
All	16	8.59	3.84	3.52	1.13	1.92	1.61	0.31	39	51.5	234	778	8.02
							Rainfall						
2007	1	46.8	5.11	40.8	0.09	0.81	0.49	0.32	820	na	260	1410	8.20
2009[w]	2	4.42	4.29	0.06	0.04	1.43	0.11	1.32	594	0.42	59	120	8.25
2010	7	20.1	4.45	14.9	0.35	5.13	4.84	0.29	95	2.42	14	368	8.10
2011	12	13.7	4.35	8.95	0.33	2.79	2.72	0.08	19	119	620	1574	8.27
2012	3	9.71	2.79	6.86	0.06	1.14	1.02	0.12	71	103	1733	1363	8.29
All	25	15.6	4.21	10.9	0.27	3.06	2.81	0.26	105	76.4	544	1129	8.22

[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, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] There was no snowmelt runoff in 2010 and no rainfall runoff in 2008.
[x] na = not available. Chloride was added late July2008.
[w] The n value was 1 for TSS, Cl, *E. coli*, EC, and pH because of missing data on July 27, 2009.

Direct contribution from the field may have differed between the two runoff event types. The field was considered a particular risk for P loss because of the moderately-high STP values. It was observed that snowmelt runoff often originated from snow and ice accumulated in the grass drainage channel and not from the surrounding field at this site. Winters in southern Alberta are subject to warm Chinook winds, which lead to a reduction in snowpack on exposed fields by sublimation, and therefore, much of the snowmelt runoff can be due to snow and ice built up in protected and low areas, such as drainage channels. Aspect and orientation of drainage channels are factors that can affect how snow is distributed on the landscape. Runoff generated from rainfall likely included a larger contributing area including portions of the field. This may be why concentration of N and P, particularly dissolved forms, were higher in rainfall runoff compared to snowmelt runoff.

The majority of TN and TP were in dissolved forms, particularly for rainfall runoff (Table 3.80 and Figure 3.107a,b). For snowmelt, 54% of TN and 84% of TP were in dissolved forms, and for rainfall runoff, 72% of TN and 92% of TP were in dissolved forms (Table 3.80). During rainfall runoff events, sediment loss may have been reduced because of increased filtration with new growth of vegetation in the field and drainage channel.

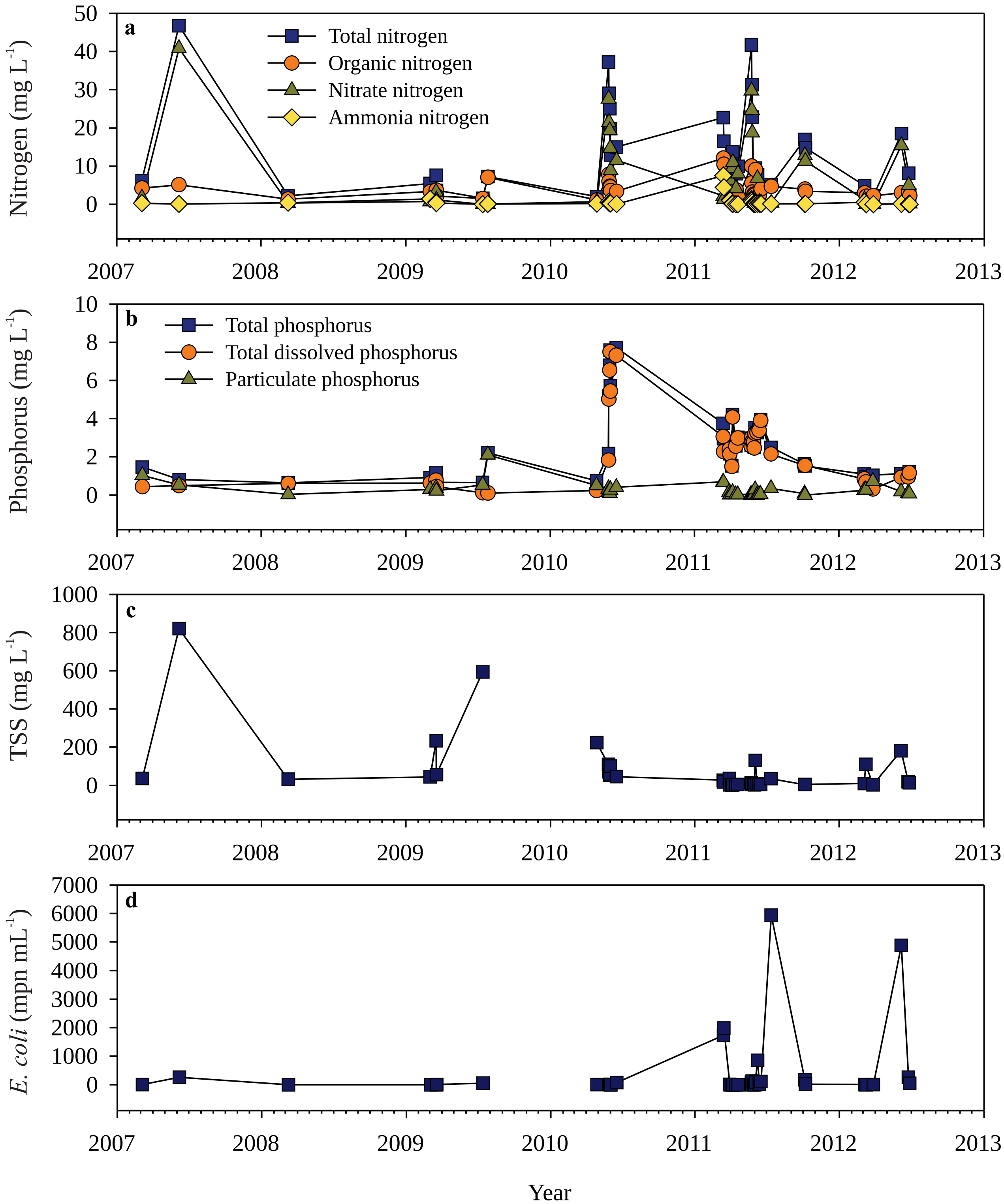

Figure 3.107. Concentration values for (a) total nitrogen, organic nitrogen, nitrate nitrogen, and ammonia nitrogen; (b) total phosphorus, total dissolved phosphorus, and particulate phosphorus; (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) at the Dairy Manure Field from 2007 to 2012.

The year 2011 resulted in the highest concentrations of most measured parameters in snowmelt runoff with the exception of PP and TSS (Table 3.80). The January to March precipitation (i.e., snowfall) in 2011 was 20% greater than the 30-yr average and higher than the other study years (Sub-section 3.2). The volume of snowmelt runoff in 2011 was not only much greater than during other years, but it also was much greater than the annual runoff volume (snowmelt and rainfall) of the other study years. The larger snowmelt runoff in 2011 may have contributed to the higher water quality parameter concentrations in the runoff water. The reasons why snowmelt PP and TSS concentrations were not the highest in 2011 may be related to the high speed at which snowmelt occurred and the slower thawing of the soil surface, which may have reduced sediment loss.

This trend of high water quality parameter concentrations in snowmelt runoff was not observed in rainfall runoff during 2011. The highest concentration for most parameters during rainfall runoff occurred in 2007, 2009, and 2010 (Table 3.80). There was less consistency in terms of parameter concentration variation among study years for rainfall runoff; however, the concentrations of TN, ON, NO_3-N, and TSS were particularly high in 2007 rainfall runoff. These high parameter concentrations may have been due to the monitoring station being installed in spring 2007. At the request of the landowner, a deeper excavation was created into the grass channel to help with drainage in the northeast corner of the field (Figure 3.108). This likely resulted in more soil erosion during runoff. With time, the excavated channel likely became more stable, resulting in less soil loss. Except for the high concentration of TN in 2007, the highest concentration of TN and TP occurred in 2010 and 2011 (Figure 3.107a,b), corresponding to the years with the two highest flows during the study (Table 3.79).

The overall average TP concentration in runoff (snowmelt and rainfall) was 2.6 mg L^{-1}. For a soil with an average STP concentration of 126 mg kg^{-1}, this concentration of TP in runoff was higher than expected based on work by Little et al. (2007) who examined the relationship between P in field runoff and STP. Some reasons for the higher TP concentration in runoff at this site may include drainage channel characteristics (e.g., vegetated versus non-vegetated), P release from residual plant material, and the variable distribution STP in the field caused by the non-uniform method used to spread manure.

Annual nutrient and TSS loads in runoff were much larger in 2010 and 2011 than the other study years (Table 3.81). This high nutrient loading was due to a combination of larger flows in 2010 and 2011 as well as higher in-stream concentrations for several parameters (e.g., TN, NO_3-N, TP, and TDP).

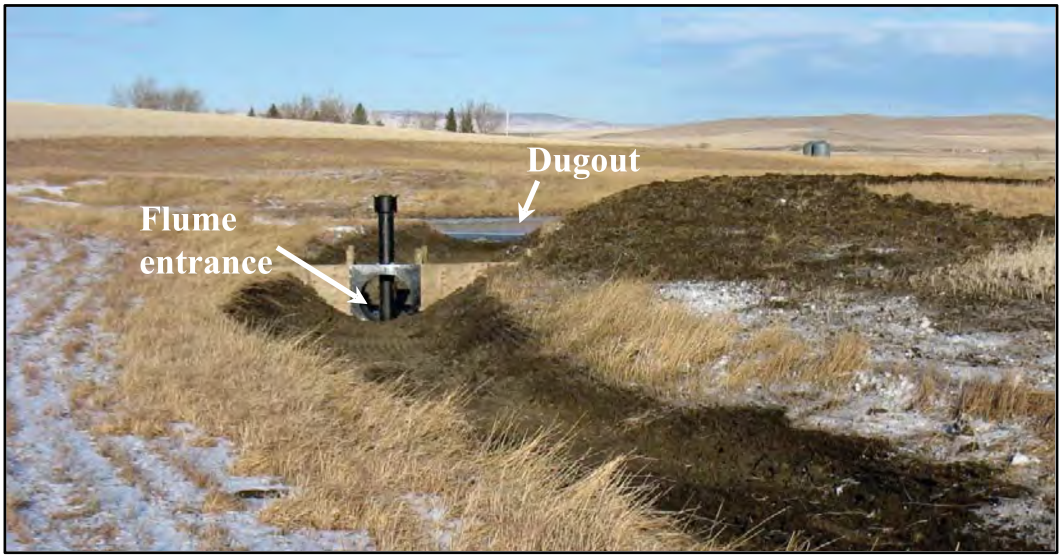

Figure 3.108. Excavation carried out in the drainage channel during the installation of the water monitoring station at the Dairy Manure Field in April 2007.

Table 3.81. Annual loads of nutrients and total suspended solids in runoff at the Dairy Manure Field from 2007 to 2012.

Year	TN [z]	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
	($kg\ yr^{-1}$)							
2007	0.96	0.11	0.84	<0.01	0.02	0.01	0.01	16.9
2008	0.03	0.02	0.01	0.01	0.01	0.01	<0.01	0.48
2009	1.45	0.89	0.43	0.11	0.29	0.14	0.15	76.9
2010	59.4	13.1	44.8	0.69	23.1	21.9	1.14	191
2011	273	106	132	32.9	60.7	56.0	4.67	322
2012	7.54	3.01	4.44	0.09	1.29	1.10	0.19	46.4

[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.
[y] No flow data were collected during snowmelt 2007 because the flow instrumentation was not operational.

3.10.4 Conclusions

- After only 1 yr of implementation, the BMP plan was discontinued and the producer returned to the previous practice of manure application on the DMF site. Partly, this was due to weather and field conditions making the application of manure to an alternative field less attractive.

- The main goal was to reduce STP in order to reduce the risk of P loss in runoff. However, several years of no P additions, including manure, would be required to reduce STP. As with the SMF, this site demonstrated circumstances that may prevent successful implementation of BMPs.

- Average STP concentration in the top 15 cm was 126 mg kg^{-1}, which was about double the agronomic threshold. Applying manure repeatedly to the DMF was convenient to the producer because of its close proximity and ease of access, but this has resulted in the moderately-high STP concentration.

- The lack of adequate storage required manure to be applied daily from September to May season. Winter application is generally not considered a good practice. Adequate storage would be required in order to prevent winter application of manure at this site.

- Even though manure was only applied on a small area (<2 ha) each year, it was estimated the application rates were very high, well in excess of crop N and P requirements.

- The concentrations of STP and soil NO_3-N were highly variable within the field, and this variability was likely the result of the non-uniform manure application method used at this site.

- This site has a risk of NO_3-N leaching to shallow groundwater, particularly with high application rates of manure. Manure applied on a larger area at agronomic rates would likely reduce this risk.

- Most of the edge-of-field runoff occurred from March to June in most years. Annual flow ranged from 15 $m^3 yr^{-1}$ to greater than 20,000 m^3 yr^{-1}. Due to above average precipitation, the highest annual flows occurred in 2010 and 2011. On average among the study years, 61% of the annual flow was from rainfall. There may have been some contribution of groundwater discharge at this site during the wetter years.

- Overall, average concentrations of most water quality parameters (TN, ON, NO_3-N, TP, TDP, *E. coli*, and EC) were higher during rainfall runoff compared to snowmelt runoff.

- The majority of TN and TP were in dissolved forms, with averages ranging from 54 to 92% in dissolved form, varying with parameter and runoff type.

- The highest concentration of TN and TP occurred in 2010 and 2011, which were the years with the two highest runoff volumes. Higher concentration of TN occurred in 2007, but was believed caused by the channel excavation required for the installation of the water monitoring station.

- Field observations suggest that snowmelt runoff often originated from snow accumulation in the drainage channel; whereas, rainfall runoff likely had a larger contributing area from the field. This may partly explain the higher parameter concentrations in rainfall runoff compared to snowmelt runoff.

3.11 Reference Site

3.11.1 Introduction and Hypotheses

The REF site was selected as an annually cropped field that was managed with common agronomic practices used in the area and without manure application for at least 5 yr. The site was under cereal production and cattle grazed the field in the fall after harvest. Runoff from a portion of the field drained through a single channel, and the runoff was monitored using a single, edge-of-field station.

Originally this site was selected as a non-manured field to serve as a reference site for runoff water quality, and to be compared to other sites in the watershed where BMPs were implemented. However, once it was discovered that this site received manure from cattle during fall grazing, it was decided to take the opportunity to implement BMPs at this site, but the original site name continued to be used.

The focus of the BMP plan was on the drainage channel in the field and managing the distribution of cattle when they fall grazed the field. The assumption was that fall grazing by cattle caused fecal pat accumulation in the drainage channel, which in turn contributed dissolved nutrients in runoff. The hypothesis was:

- The implementation of cattle distribution management techniques would reduce the time cattle spent in the drainage channel, and this would reduce the nutrient and bacteria concentrations in runoff water at the edge-of-field.
  - It was expected that dissolved forms of nutrients would be reduced more than particulate forms.
  - Bacteria may not be a prevalent water quality concern, given that deposited fecal pats in the fall are exposed to winter conditions. However, a reduction was still expected.

The main component of the BMP plan was the management of crop residues so that this source of cattle feed was distributed away from the channel. This BMP was successfully implemented in fall 2009. Unfortunately, the BMP could not be implemented in the two subsequent years because of a crop failure in 2010 and harvesting of the crop as silage in 2011. In addition, the cattle were unexpectedly attracted to the monitoring station near the exit point of the drainage channel and this likely affected water quality in the pre-BMP period. Plus, a major change in land management in 2012 precluded comparison of 2012 data to pre-BMP data. And finally, high flows in 2010 and 2011 caused water to back up from a nearby tributary and flood the monitoring station and this prevented flow measurements and consistent water sampling. Because of these factors, an assessment of BMPs at this site could not be carried out in order to test the hypothesis. Instead, the results are used as an opportunity to document the runoff water quality and management practices for a single agricultural field during a 5-yr period.

3.11.2 Methods

3.11.2.1 Site Description and Management

The REF site was in the northern part (Figure 3.3) and lower region (Figure 3.2) of the watershed. The site was an annual cropped field, irregular in shape, and about 72 ha in size (Figure 3.109). Indianfarm Creek was a short distance from the east side of the field. A tributary of IFC was nearby along the south and west sides of the field. Narrow, native pasture land was along these reaches of IFC and the tributary. A portion of the field (about 19 ha) drained to a point along the west side of the field near the southwest corner. The drainage channel from the field exited the site and followed a vegetative channel and connected to the tributary about 193 m downstream from the west edge of the field. The field was also used to fall graze cattle after harvest. In 2012, the size of the field was increased when adjacent native pasture along the west, south, and east sides of the field was converted to cropland.

The REF site was in the CWY1/U1l soil landscape model, as described by AGRASID (Alberta Soil Information Centre 2013). The soils in this model are Calcareous and Rego Black Chernozems, and includes dominant (60% or more) Cowley soil series and significant (10 to 30%) Cowley-ZR soil series, with well drained characteristics. The landform in the model is described as undulating, low relief with a limiting slope of 2%, and parent material consists of fine-textured, water-laid sediments. The surface soil had a clay texture (15% sand, 46 % clay), pH of 7.5, electrical conductivity of 0.9 dS m^{-1}, 2900 mg kg^{-1} TN, 908 mg kg^{-1} TP, and 7% organic matter (Appendix 4).

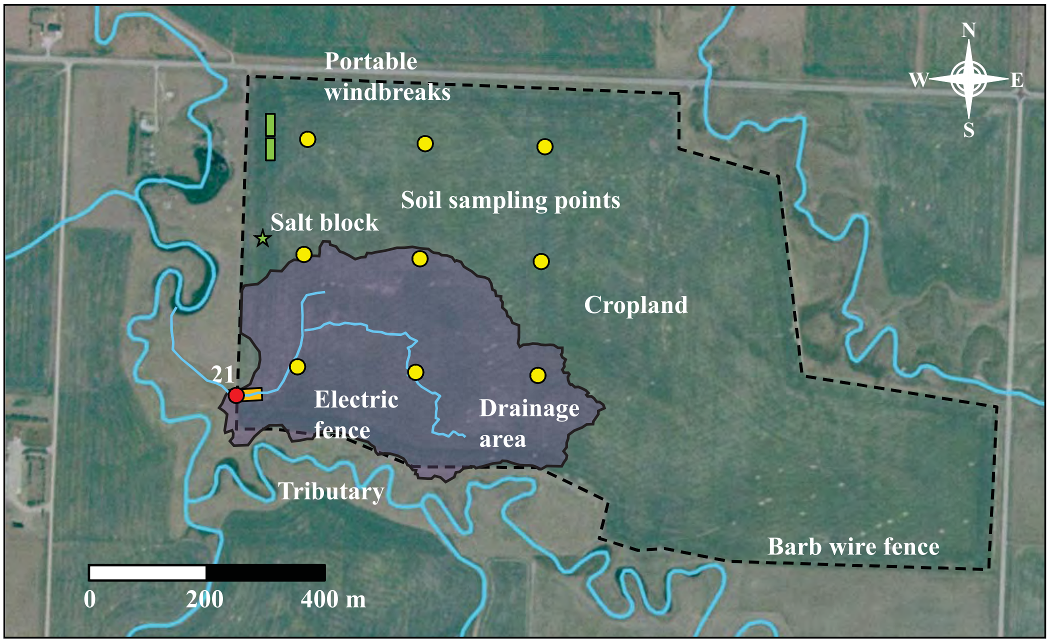

Figure 3.109. The Reference site showing the field boundaries, the drainage area to Station 21, and agronomic soil sample points.

The site was seeded to barley from 2007 to 2011 and seeded to canola in 2012 (Table 3.82). Barely was harvested as grain in 2007 to 2009 and as silage in 2011. In 2010, because of poor yield, the barley crop was swathed and left in the field for cattle to graze. Commercial fertilizer was applied either before seeding and/or with the seed. Weed control included pre-seeding and in-crop applications of herbicides (Table 3.83). Generally, zero-tillage was practiced and barley was direct seeded. However, cultivation was carried out in May 2010 for weed control, and in the same year, light cultivation was used to incorporate broadcasted seed on June 25 when the field was re-seeded.

The REF site was generally grazed by cattle in the fall after harvest. The number of animals per year ranged from 22 to 60 and the time they grazed the field ranged from 3 to 10 wk yr^{-1} (Table 3.84). During harvest of the barley crops, straw and chaff from the combine were collected into piles rather than spread on the field. The piles were deposited throughout the field and cattle fed from the piles in the fall. In 2010, because of poor yield, the crop was swathed and not combined. The swathes were left in the field for cattle to graze. In 2011, the barley crop was harvested as silage and no swathes or straw/chaff piles were left in the field. Prior to the fall grazing season, the cattle grazed in the adjacent pastures on the south and west sides of the REF site (Figure 3.109). When cattle fall grazed at the REF site, they also had access to the pasture east of the site. Cattle were able to obtain water from a dugout in the pasture on the west side of the REF site.

3.11.2.2 Implementation of Beneficial Management Practices

Water quality data collected showed relatively high nutrient concentrations (Sub-section 3.11.3.3). The source of high nutrient concentration in runoff was likely from fecal pats deposited in the field drainage channel when the cattle grazed in the fall. Straw/chaff piles were deposited

Table 3.82. Agronomic management practices at the Reference site from 2007 to 2012.

					Fertilizer nutrient				
			Harvest	Yield	N	P	K	S	B
Year	Crop	Seeding date	date	(Mg ha^{-1})	(kg ha^{-1})				
2007	Barley	na[z]	na	na	na	na	na	na	na
2008	Barley	mid May	Sep	4.57	67[y]	17[y]	-	-	-
2009	Barley	May 20	Sep 14	3.76	112[x]	-	-	-	-
2010	Barley	Jun 25[w]	Sep 15[v]	0.34	39.2[u]	-	-	-	-
2011	Barley silage	May 17 / Jun 24[t]	Sep 16	7.85	108.5[s]	9.7[y]	18.8[r]	2.8[r]	-
2012	Canola	Apr 18	Sep 20[q]	3.8	133	9.1	17.3	43.7	1.12

[z] na = not available.
[y] Fertilizer applied with the seed.
[x] Fertilizer was applied on May 13 prior to seeding.
[w] The crop was seeded by broadcasting the seed followed by a light cultivation and harrowing.
[v] Due to poor yield, the crop was swathed and left in the field for cattle grazing. The grain yield is estimated.
[u] Broadcasted N fertilizer on March 13.
[t] Due to wet conditions, the crop was re-seeded on June 24.
[s] 90.6 kg ha^{-1} N was broadcasted as 46-0-0 in April 2011 and 17.9 kg ha^{-1} N was placed as 16-20-0-13 with the seed.
[r] Assumed a 1:1 mixture of 0-0-52-17 and 0-0-85 applied at 33 kg ha^{-1}.
[q] Estimated.

Table 3.83. Herbicides applied at the Reference site from 2007 to 2012.

Year[z]	Pre-seeding application	In-crop application
2009	Glyphosate, 2,4-D (May 13)	na[y]
2010[x]	tribenuron-methyl, metsulfuron-methyl, and quizalofop-p-ethyl (Apr 23)	bromoxynil and MCPA (Jul 21)
2011	florasulam + glyphosate, tanked mixed with extra glyphosate (early May)	bromoxynil and MCPA (Jul 21)
2012	glyphosate + tribenuron-methyl (early Apr[w])	Glyphosate (Jun 20)

[z] Herbicide use information was not available for 2007 and 2008.
[y] na = not available.
[x] The field was cultivated on May 24 and 25 for weed control.
[w] Estimated.

Table 3.84. Fall grazing by cattle at Reference site from 2007 to 2011.

Year	Dates in field	Livestock[z]	Days in field
2007	na[y]	na	na
2008	Oct 1 to Dec 10	55 cc	71
2009	Sep 21 to Nov 7	60 c	36
2010	Jan[x]	50 cc + 4 yaks	31[x]
2010	Sep 15 to Oct 8	21 cc + 1 b	24
2010	Oct 8 to Nov 26	36 cc + 2 b	48
2011	Sep 19 to Oct 27	48 cc + 2 b	38

[z] c = cows, cc = cow-calf pairs, b = bull.
[y] na = not available.
[x] Estimates.

throughout the field, including the drainage channel. These piles attracted cattle to the channel resulting in a concentration of fecal pat and urine deposits near the locations of the piles (Figure 3.110a). Also, the monitoring station (flume, wooden wing wall, and equipment shed) was installed along the west side of the field, and this unintentionally attracted cattle and caused an accumulation of fecal pats a short distance upstream from the monitoring station (Figure 3.110b). Even though the latter was not a result of normal management practices, it did create an artificial attraction for cattle to the channel.

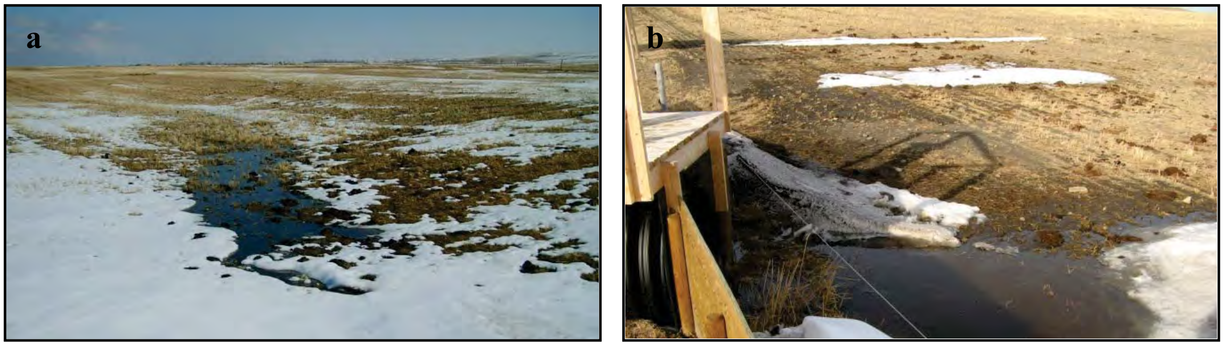

Figure 3.110. The accumulation of fecal pats in the (a) drainage channel and (b) near the water monitoring station at the Reference site in March 2009.

After 2 yr of runoff water monitoring (2008 to 2009), BMPs were implemented in fall 2009. The BMP plan included techniques to reduce the attraction of cattle to the drainage channel. During harvest in 2009, straw/chaff piles were not placed in or near the drainage channel. Unfortunately, because of poor crop growth in 2010, the crop was swathed and the swathes left in the field for cattle to graze in the fall. Therefore, swathes were present in the drainage channel and likely attracted cattle, and as a result, this part of the BMP could not be implemented in 2010. In 2011, the barely crop was harvested as silage, and no swathes or piles of crop residue were left in the field. Therefore, in terms of crop residue for cattle feed in the field, the drainage channel was no less attractive for cattle compared to the rest of the field in 2010 and 2011.

Two portable windbreaks (2.6 m high by 9.3 m long) and salt blocks were placed in the field during fall grazing from 2009 to 2011 (Figure 3.111). These cattle distribution tools were used to attract cattle away from the drainage channel. The windbreaks and salt blocks were placed at different locations within the field each year.

To prevent cattle from using the water monitoring station for shelter and to keep the cattle out of this part of the drainage channel, an area 20 m wide and 30 m upstream of the monitoring station was cordoned off with an electric fence each fall from 2009 to 2011. In September 2010, cattle were placed in field 12 d before the electric fence, windbreaks, and salt blocks were deployed. As a result, cattle were able to access the channel immediately upstream from the monitoring station during the first 12 d of the 72-d period they were in the field (Figure 3.112).

3.11.2.3 Soil

Soil characterization samples (Sub-section 2.9) were collected from five sampling points on October 16, 2008. Agronomic samples (0 to 15 cm) were collected annually (2007 to 2012) from nine sampling points in a 200- by 200-m grid (Figure 3.109). Soil-test samples (0 to 60 cm) were collected in fall 2009 and fall 2010 to develop nutrient management plans for the 2010 and 2011 crop years, respectively. In 2009, soil-test samples were collected from six transects. Due to time constraints in 2010, soil-test samples were collected at the same time as the agronomic samples using the grid sampling points.

Figure 3.111. Portable windbreaks (left) and a salt block (right) at the Reference site in late September 2010.

Figure 3.112. Pugmarks in the drainage channel caused by cattle prior to deployment of the electric fence to cordon off this area in September 2010.

Soil samples were collected from the drainage channel on September 28, 2011 to determine if there were differences in soil nutrient concentrations between the channel and the whole field. Samples were collected from 0 to 15 cm in the centre of the drainage channel at five sampling points in 20-m intervals starting 25 m east of the monitoring station. At each sample point, five samples were collected in a 1-m radius using a Dutch auger and the samples were mixed to create a composite sample.

Pre- and post-seeding soil samples were collected to determine the effect of commercial fertilizer application on plant available N and P in spring 2011. The samples were collected using a Dutch auger from 0- to 15-cm on May 3 (pre-seeding) and June 14 (post-seeding; also the annual spring agronomic samples). The same sampling methodology was used as described for the agronomic samples (Sub-section 2.9).

3.11.2.4 Water Flow and Quality Methods

This site was equipped with a single, edge-of-field water monitoring station (Station 21), which included a circular flume, automatic Isco water sampler, wooden wing walls to direct runoff, and an instrumentation shed (Figure 3.113). Station 21 was installed in fall 2007 and 5 yr (2008 to 2012) of runoff events were monitored at this site. The monitoring station was near the southwest corner and along the west side of the field where the 19-ha drainage area exited the field (Figure 3.109). An electric fence was erected around the station to protect it from cattle in the west pasture. Pre-BMP water samples were collected in 2008 and 2009 and post-BMP samples were collected from 2010 to 2012. A total of 17 snowmelt runoff samples and 16 rainfall runoff samples were used to assess water quality at this site.

In 2010 and 2011, heavy rainfall events caused water from the tributary to back up into the circular flume (Figure 3.114). Therefore, rainfall runoff flow could not be measured and water samples collected by the Isco sampler were considered contaminated by the tributary water and these samples were not used. However, grab samples were collected during rainfall runoff from the field drainage channel about 20 m upstream from Station 21 where active runoff from the field was not affected by the water from the tributary.

Figure 3.113. Station 21 at the Reference site on March 13, 2009.

Figure 3.114. Station 21 flooded with backed up water from the tributary on May 24, 2011.

3.11.3 Results and Discussion

3.11.3.1 Implementation of Beneficial Management Practices

The BMP plan was successfully implemented in fall 2009. The straw/chaff piles were placed away from the drainage channel, removing these points of attraction for cattle. In 2010, the BMPs were deployed, including the electric fence upstream of Station 21, nearly 2 wk after the cattle started grazing in the field. As a result, the cattle congregated next to Station 21 and had an obvious impact on the drainage channel (Figure 3.112). Also in 2010, because of poor growth, the barley was swathed and left in the field, including the drainage channel, and was grazed by the cattle. Therefore, the BMP of keeping crop residue for feed out of the drainage channel was not achieved in 2010. In 2011, the barley crop was harvested for silage. Therefore, the drainage channel was no less attractive to cattle compared to the rest of the field in 2011. It was observed that the cattle only used the portable windbreaks during poor weather. As such, cattle still accessed and grazed the drainage channel, and the windbreaks likely had minimal influence in attracting cattle away from the channel area. The collection of cattle distribution and behavior data would have been required in order to make a better assessment of the effectiveness of the windbreaks.

The cost of the BMPs was relatively low, with a total cost of $2766 (Table 3.85). Most of this cost (90%) was for the two portable windbreaks.

Table 3.85. Cost of beneficial management practices at the Reference site.

Year	Item	Cost ($)	Labour (h)
2009	Portable windbreaks (2)	2500	1
	Salt blocks (2)	30	-
	Soil sampling[z]	103	4
	Nutrient management plan	-	1
	Sub-total	**2633**	**6**
2010	Portable windbreaks	-	1
	Salt blocks (2)	30	-
	Soil sampling[z]	103	4
	Nutrient management plan	-	1
	Sub-total	**133**	**6**
2011	Portable windbreaks	-	1
	Salt blocks (2)	30	-
	Sub-total	**30**	**1**
	Grand total	**2766**	**13**

[z] Laboratory analysis at $34.25 per sample.

3.11.3.2 Soil

Agronomic samples. Extractable N and STP concentrations were not excessive in the 0- to 15-cm soil layer at this site. The 5-yr average concentration was 13 mg kg^{-1} for NO_3-N, and 7 mg kg^{-1} for NH_4-N. There was no consistent trend among the study years (Table 3.86). In general, the average NO_3-N and NH_4-N concentrations were higher in the spring compared to the fall. Spring NO_3-N concentration was on average nearly three times higher in the spring than in the fall. The concentrations of NO_3-N and NH_4-N in the spring were noticeably higher in 2008, 2009, and 2012 compared to 2010 and 2011 (Table 3.86). This difference may be a combination of differences in spring precipitation and the time between seeding and when the soil samples were taken. In 2010 and 2011, precipitation was well above average (Sub-section 3.2) and the soil samples were collected 1 to 2 mo after seeding. Increased precipitation may have caused NO_3-N leaching and denitrification before samples were collected. In the other 3 yr, soil sampling was carried out within 1 to 2 wk after seeding and no large precipitation events occurred between seeding and sampling. These soil samples may have captured the influence of recently applied N fertilizer.

The 5-yr average concentration of STP was 38 mg kg^{-1}, with a range from 22 to 70 mg kg^{-1} (Table 3.86). The average concentration was less than the agronomic threshold of 60 mg kg^{-1}. This supports that the field had not received manure application in recent years prior to the study. Based on the STP concentration, this field should have a relatively low risk of P loss in runoff, and this is typical for a non-manure field. Unlike extractable N, STP concentration was similar between spring and fall. Plus, the concentration of STP was less variable among years than was observed for extractable N.

Soil-test samples. The soil-test sample results for the 0- to 15-cm soil layer in 2009 and 2010 (Table 3.87) were similar to the agronomic soil sample fall results (Table 3.86). Concentrations tended to be smaller in the 15- to 60-cm layer, particularly for STP. Using the AAFIRM program and the fall 2009 soil-test results, fertilizer recommendations for the 2010 crop year were 45 kg ha^{-1} N and no application of P. Using the 2010 soil-test results, fertilizer recommendations for the 2011 crop year were 55 kg ha^{-1} N and 4 kg ha^{-1} P. For these recommendations, it was assumed the crop

Table 3.86. Average nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) concentrations in agronomic soil samples collected from 2007 to 2012 at the Reference site.

	NO_3-N		NH_4-N		STP	
	Spring	Fall	Spring	Fall	Spring	Fall
Year	(mg kg^{-1})					
2007[z]	-	11	-	6	-	39
2008	33	5	16	6	50	70
2009	18	5	11	5	36	34
2010	7	4	5	6	30	30
2011	9	9	3	4	35	22
2012[z]	27	-	10	-	32	-

[z] No soil samples were collected in spring 2007 and fall 2012.

was feed barley, spring soil conditions were wet, growing season precipitation was good, and current cost of fertilizer and crop values at the time of the recommendations. The actual fertilizer application in 2010 (Table 3.82) was similar to the above recommendations based on AFFRIM. However, the amount of N and P fertilizer applied in 2011 was about twice the recommended rates.

Drainage channel samples. The concentration of extractable NO_3-N fluctuated slightly along the length of the drainage channel while the concentration of NH_4-N remained relatively stable (Table 3.88). The concentrations of both extractable N parameters in the channel were similar to the values reported for the whole field in the fall (Table 3.86), with NO_3-N average concentration in the channel (14 mg kg^{-1}) only slightly higher than in the field in fall 2011 (9 mg kg^{-1}).

Soil-test P concentration was higher in the drainage channel compared to the field, ranging from 81 to 126 mg kg^{-1} among the five sampling points (Table 3.88). The concentration of STP was highest near the outlet of the channel by Station 21. The average STP concentration was nearly five-fold higher in the drainage channel compared to average STP concentration for the whole field in fall 2011 (Table 3.86). When compared to the 5-yr average for the fall agronomic samples (38 mg kg^{-1}), the average STP concentration in the channel was nearly three-fold higher. The average STP concentration for the whole field, as determined by the agronomic samples (Table 3.86), suggest that this field did not have excess STP and should be low risk for P loss in runoff. In fact, based on the 2010 soil-test sample results (Table 3.87), P fertilizer was recommended for the 2011 crop year. However, the STP in the drainage channel had moderately high STP concentration and was well above the agronomic threshold of 60 mg kg^{-1}, particularly near the outlet. The reason why STP concentration was higher in the channel is not clear. The field was relatively flat and the drainage channel shallow (Figure 3.110a) and easily farmed through. Prior to fall 2009, chaff piles were deposited in the drainage channel and these piles attracted cattle during fall grazing. However, the distribution of chaff piles would have been the same throughout the field. Perhaps the channel area provided some shelter for the cattle, however, it would have been minimal. The higher STP concentration closer to Station 21 provided evidence that the monitoring station attracted cattle in 2007 and 2008, prior to erecting the electric fence in 2009 on the east side of the station to keep cattle way. As described previously, the installation of the fence was delayed 12 d after cattle were placed in the field in 2010, and this allowed cattle access to the channel immediately upstream from the station (Figure 3.112). Without quantitative data on cattle movement and distribution during fall grazing, it is difficult to determine whether or not the higher

Table 3.87. Nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) concentrations in the soil-test samples collected at the Reference site in 2009 and 2010.

	2009			2010		
Soil layer (cm)	NO_3-N	NH_4-N	STP	NO_3-N	NH_4-N	STP
	(mg kg^{-1})					
0 to 15	4	5	39	4	7	30
15 to 30	3	5	2	1	3	1
30 to 60	3	4	1	1	2	1

STP concentration in the drainage channel was caused by cattle grazing in the fall. Another possibility may be if crop growth in the channel was reduced in some years due to wet conditions, the uptake of applied P fertilizer may have been reduced, and with time a slow build-up of STP occurred.

Pre- and post-seeding samples. The intent of the collected pre- and post-seeding soil samples was to determine if the application of commercial fertilizer could be detected. This approach assumed that fertilizer was applied at the time of seeding. It was learned later that most (90%) of the commercial fertilizer N was applied prior to seeding and the collection of the pre-seeding soil samples at this site in 2011. Nitrogen fertilizer was applied (91 kg ha^{-1} N) to the field in April 2011 and a small amount of N (18 kg ha^{-1}) was applied with the seed in 2011 (Table 3.82). The increase in NO_3-N concentration from 3 mg kg^{-1} in the pre-seeding samples to 9 mg kg^{-1} in the post-seeding samples (Table 3.89) could have been the result of the added N fertilizer with the seed. However, the pre- and post-seeding values were not statistically different. Assuming no losses of N, and that added N was in the form of NO_3, or converted to NO_3, and soil bulk density was 1200 kg m^{-3}, the addition of 18 kg ha^{-1} N could increase soil NO_3-N by about 10 mg kg^{-1} in the 0- to 15-cm layer.

Using the same assumptions, the application of 91 kg ha^{-1} N would have increased NO_3-N concentration by 50 mg kg^{-1}. However, the pre-seeding soil samples, which were collected within 2 wk of the fertilizer being applied in April, contained only 3 mg kg^{-1} NO_3-N (Table 3.89). The fertilizer used was urea (46-0-0) and the urea needs to be first converted to NH_4 and then to NO_3 in the soil. Possibly, very little conversion had occurred by the time the soil samples were collected. Plus, if the urea fertilizer was not incorporated, some of the added N likely was lost due to NH_3 volatilization.

Phosphorus fertilizer was applied with the seed in 2011 (9.7 kg ha^{-1} P). Pre-seeding soil sampling was 2 wk before seeding and post-seeding sampling was about 1 mo after seeding. The concentration of STP increased by about 20% from pre- to post-seeding, though, the difference was not statistically significant (Table 3.89). Theoretically, the application of 9.7 kg ha^{-1} P could increase STP by approximately 20% in the 0- to 15-cm soil layer with an initial soil concentration of 29 mg kg^{-1} P, assuming a soil bulk density of 1200 kg m^{-3}. However, this may not necessarily mean an increased risk of P loss with a slightly higher STP concentration. In this case, P was applied with the barley seed, which was likely seeded to a depth of about 5 cm. Generally the zone

Table 3.88. Average nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) concentrations for soil samples (0 to 15 cm) collected from the drainage channel on September 28, 2011 at the Reference site.

Sample	Distance from Station 21 (m)	NO_3-N	NH_4-N	STP
		(mg kg^{-1})		
1	25	12	4	121
2	45	18	4	126
3	65	10	5	81
4	85	25	4	81
5	105	7	5	94
Average		14	4	101

Table 3.89. Average nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) concentrations in pre- and post-seeding soil samples collected at the Reference site in 2011.

	NO_3-N	NH_4-N	STP
	------------------------------	(mg kg^{-1})	------------------------------
Pre-seeding[z]	3*a*[y]	3*a*	29*a*
Post-seeding[x]	9*a*	3*a*	35*a*

[z] Pre-seeding samples collected on May 3, 2011. The barley crop was seeded on May 17, 2011.
[y] Averages for each parameter followed by the same letter were not significantly different (*P* <0.1).
[x] Post-seeding samples collected on June 14, 2011.

of interaction between runoff water and the soil surface is within the top 1 cm of the soil. The added P was likely protected from runoff loss when placed with the seed. Plus in fall 2011, the STP concentration was reduced to 22 mg kg^{-1} (Table 3.86), suggesting that more than the applied P was removed by the crop within one growing season.

3.11.3.3 Water Flow and Quality

Water flow. The annual flows at Station 21 could not be determined in 2010 and 2011 because water from the tributary backed up and flooded the circular flume during the high precipitation events in these years (Figures 3.114 and 3.115 and Table 3.90). Even though total volumes could not be measured, the runoff from the REF site in 2010 and 2011 was qualitatively much larger compared to the other 3 yr based on field observations. This was true for all of the edge-of-field sites in IFC Watershed in 2010 and 2011. Excluding 2011, about 72% of the runoff flow on average was caused by rainfall during the study (Table 3.90). No snowmelt runoff occurred in 2010 and 2012. In 2011, snowmelt and rainfall runoff occurred; however, the proportions between the two event types could not be determined because the majority of flow was not measured. Flow data for other edge-of-field sites in IFC Watershed (NMF, DMF, and SMF) showed that 57 to 67% of runoff was caused by rainfall in 2011. Field observations at the REF site suggest rainfall runoff was also dominant at this site. During the study, snowmelt runoff was only dominant in 2009, with very little rainfall runoff at this site.

Water quality. On average, the concentrations of NH_3-N, TP, TDP, and Cl were higher in snowmelt runoff compared to rainfall runoff (Table 3.91). The opposite was true for pH and concentrations of TN, ON, NO_3-N, PP, TSS, *E. coli*, and EC, which all were higher in rainfall runoff. The concentration of NH_3-N was particularly high in March 2009 snowmelt (21 mg L^{-1}) and this was followed by high NO_3-N concentration in rainfall runoff (28 mg L^{-1}) in the latter part of June 2009 (Figures 3.115 and 3.116a), accounting for most of the TN in both cases. Prior to fall 2009, cattle lingered in close proximity to the monitoring station, which was a point of attraction for the cattle. There was likely an accumulation of fecal pat and urine deposits immediately upstream from the monitoring station, and this may have been the source of NH_3 in March 2009. On May 13, 2009, N fertilizer was applied (112 kg ha^{-1}) 7 d prior to seeding (Table 3.82), and this may have contributed to a peak concentration of NO_3-N in the runoff event in late June 2009 (Figure 3.115). However, TP, TDP, and *E. coli* also peaked during this event, and no P fertilizer was applied in 2009. In contrast to 2009, high concentrations of NH_3-N and NO_3-N in runoff were not observed in 2008 (Figure 3.116a).

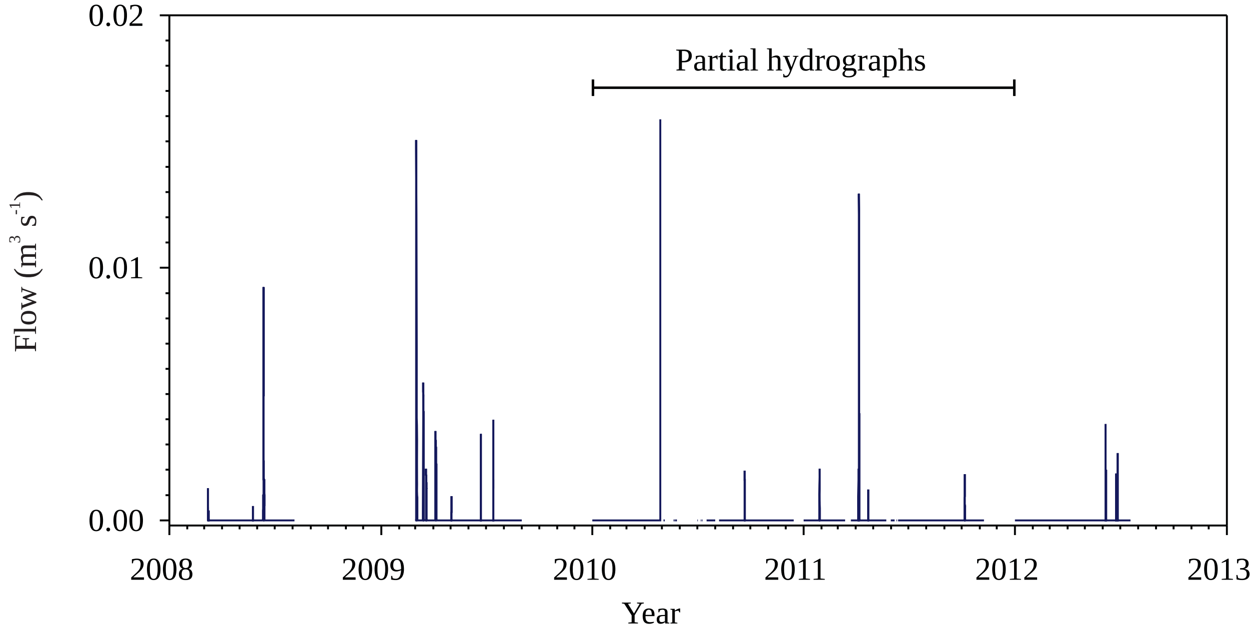

Figure 3.115. Annual hydrographs for Station 21 at the Reference site from 2008 to 2012. Note that the hydrographs for 2010 and 2011 are incomplete due to missing data.

Table 3.90. Annual flow and proportion attributed to snowmelt and rainfall runoff at the Reference site from 2008 to 2012.

Year [z]	Flow (m^3 yr^{-1})	Proportion from snowmelt (%)	Proportion from rainfall (%)
2008	426	15	85
2009	2335	96	4
2010	na[z]	0	100
2011	na	< rainfall	> snowmelt
2012	48	0	100

[z] na = not available. The majority of flow was not measured in 2010 and 2011 because water backed up from the tributary into the circular flume at Station 21.

Other notable differences between snowmelt and rainfall runoff at this site included NO_3-N, *E. coli*, and TSS. On average, NO_3-N concentration was 17-fold greater in rainfall runoff than in snowmelt (Table 3.91). This was driven by higher concentrations in rainfall runoff in 2009, 2011, and 2012. Similarly, *E. coli* concentration was 19-fold greater in rainfall runoff compared to snowmelt. This was likely due to more microbial activity during the warmer conditions during rainfall runoff. The highest *E. coli* concentration (16,640 mpn 100 mL^{-1}) occurred on September 21, 2010 (Figure 3.116d). This spike in concentration was likely due to the presence of cattle in the drainage channel next to Station 21 prior to the runoff event. Cattle were moved into the field early in fall 2010 and the electric fence, salt blocks, and windbreaks were not yet deployed in the field.

Table 3.91. Average concentration of water quality parameters in runoff at the Reference site from 2008 to 2012.[z]

Year[y]	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli*	EC	pH
		-----	-----	-----	-----	(mg L^{-1})	-----	-----	-----	-----	(mpn 100 mL^{-1})	(µS cm^{-1})	
							Snowmelt						
2008	2	7.51	6.57	0.23	0.63	3.09	2.94	0.15	26	na[x]	65	435	7.65
2009	10	26.8	4.68	1.01	21.0	2.37	2.11	0.26	26	12.0	23	528	7.68
2011	5	5.13	2.81	1.98	0.19	2.02	1.86	0.16	18	22.4	202	627	7.88
All	17	18.1	4.35	1.20	12.5	2.35	2.13	0.22	24	15.5	81	546	7.73
							Rainfall						
2008	3	7.53	3.18	4.19	0.06	2.10	1.93	0.17	18	na[x]	274	595	7.97
2009	2	35.1	6.54	27.9	0.15	2.80	2.54	0.26	29	20.4	15	712	7.93
2010	3	13.4	3.25	9.90	0.13	2.13	1.77	0.36	60	18.3	5656	848	8.02
2011	6	36.9	10.7	21.4	3.82	1.82	1.69	0.13	33	10.5	397	926	7.99
2012	2	62.0	14.6	47.3	0.06	2.64	1.34	1.30	702	5.47	2013	765	7.88
All	16	29.9	7.87	20.1	1.49	2.16	1.81	0.34	119	13.0	1514	802	7.97

[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, Cl = Chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] No snowmelt runoff occurred in 2010 or 2012.
[x] Chloride was added in late July 2008.

As a result, the cattle were attracted by the monitoring station and fecal pats were deposited and pugging occurred within a few meters upstream from the station (Figure 3.112). Total suspended solids concentration was nearly 5-fold greater in rainfall runoff compared to snowmelt runoff. The higher TSS concentration in rainfall runoff was primarily influenced by the much higher value (702 mg L^{-1}) observed in 2012 (Figure 3.116c). The high loss of TSS was caused by the intensive tillage operation carried out on adjacent native pasture in spring 2012. When the 2012 average TSS value was removed, the average TSS in snowmelt (24 mg L^{-1}) and rainfall (35 mg L^{-1}) were of similar magnitude.

The majority of TN in runoff was in dissolved form (NO_3-N and NH_4-N). Total N in snowmelt runoff consisted of 76% dissolved N, and TN in rainfall runoff consisted of 72% dissolved N (Table 3.91). In general NH_3-N was the dominant dissolved N form in snowmelt runoff; whereas, NO_3-N was the dominant dissolved N form in rainfall runoff. Total P was also dominated by dissolved forms with an average of 91% as TDP in snowmelt runoff and 84% as TDP in rainfall runoff.

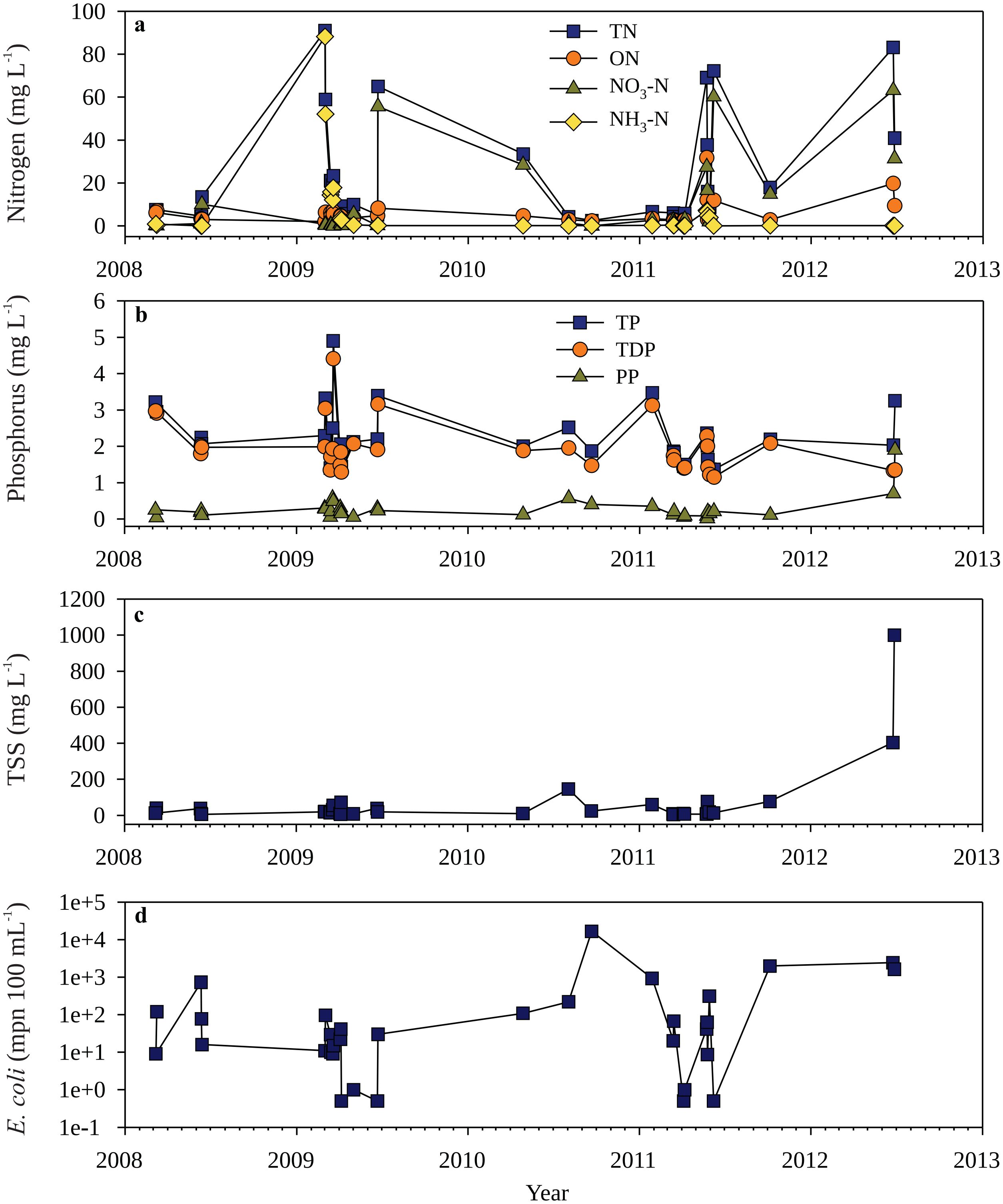

Figure 3.116. Concentration values for (a) total nitrogen (TN), organic nitrogen (N), nitrate nitrogen (NO_3-N), and ammonia nitrogen (NH_3-N); (b) total phosphorus (TP), total dissolved phosphorus (TDP), and particulate phosphorus (PP); (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) at the Reference site from 2008 to 2012.

In the absence of pre- versus post-BMP results, water quality data were compared to other BMP sites in the watershed. Average TP in runoff at the REF site (2.26 mg L^{-1}) was higher than at the NMF (1.79 mg L^{-1}) and SMF (1.17 mg L^{-1}) sites, lower than the DMF site (2.62 mg L^{-1}), and similar to the corral area (2.24 mg L^{-1}) at the PST site. Average TN in runoff at the REF site (24.8 mg L^{-1}) was higher than the other four BMP sites, which ranged from 6.6 to 18.5 mg L^{-1}. The concentration of TSS at the REF site (70 mg L^{-1}) was less than the DMF site (79 mg L^{-1}) and greater than the NMF, corral area, and SMF sites (29 to 39 mg L^{-1}). However, as indicated previously, TSS increased considerably at the REF site in 2012, possibly as a result of intensive tillage (Figure 3.117). When the 2012 results were removed (two samples) the average TSS for the REF site was 29 mg L^{-1} and comparable to most of the other edge-of-field BMP sites.

The intensive tillage (double discs) of the adjacent pasture land may have caused the large increase in TSS concentration in rainfall runoff in spring 2012 (Figure 3.116c). The average TSS concentration prior to 2012 was 29 mg L^{-1}. In 2012, average TSS concentration increased by more than 24 fold (Table 3.91), suggesting the tillage operation made the soil surface more erodible. Although the original REF field, and most of the drainage area to Station 21, was not tilled with double discs in 2012, and the drainage area shown in Figure 3.109 is only an approximation. The intensive tillage likely affected parts of the drainage area along the west and south edges. The highest average concentration of other parameters also occurred in spring 2012 including TN, ON, NO_3-N, and PP. It is interesting that this was not the case for TP, even though PP concentration was the highest in 2012. Equally interesting is that the increase in PP concentration was offset by a decrease in average TDP concentration, which was the lowest in spring 2012. One possible explanation is that the intensive tillage operation may have actually reduced the loss of dissolved forms of P. Phosphorus tends to stratify with higher concentration near the soil surface when soils are not disturbed. Intensive tillage, such as discing or plowing, can overturn and bury or partially bury surface soil higher in P, making it less accessible to surface runoff water.

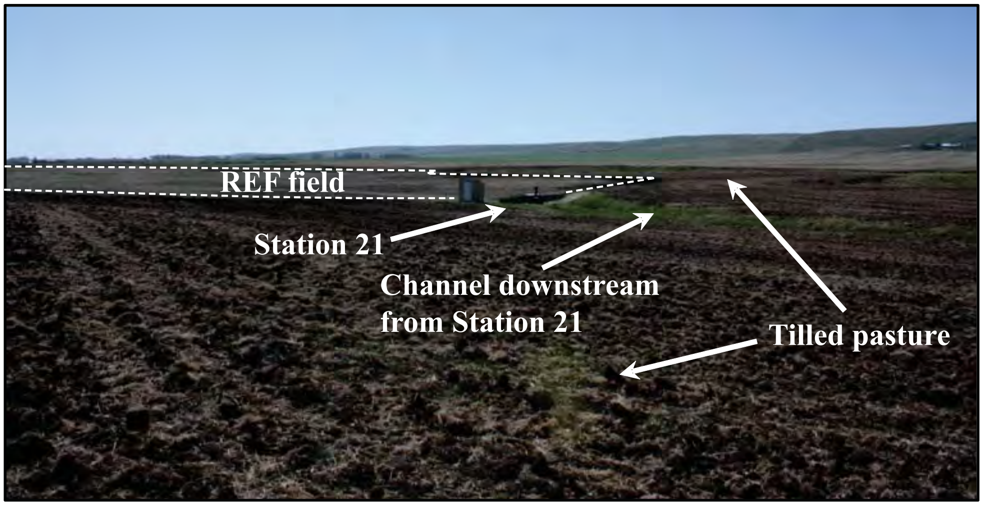

Figure 3.117. Native pasture land along the west and south sides of the Reference (REF) site after tillage with double disks. Image taken May 15, 2012.

A tillage effect on runoff water quality may have also occurred in 2010. In 2010, the field was cultivated for weed control during the latter part of May (Table 3.83) and was lightly cultivated to incorporate applied seed in late June (Table 3.82). The second highest average TSS and PP concentrations were observed in 2010 rainfall runoff (Table 3.91 and Figure 3.116c) and this may have been caused by these cultivation events.

For the study years that loads were calculated, values were the highest in 2009 compared to 2008 and 2012 (Table 3.92). This can be explained by the much higher runoff volume in 2009, which was 5 to 49 fold greater than in 2008 and 2012, respectively (Table 3.90). Interestingly, the runoff volume in 2008 was nearly nine fold greater than in 2012; however, the loads for some parameters were greater in 2012 than in 2008, including TN, NO_3-N, and TSS. This can be attributed to increased concentration of these parameters, possibly caused by the intensive tillage that was carried out in spring 2012. Even though loads could not be determined for 2010 and 2011 because of missing flow data, the loads in these years would have likely been larger than the other 3 yr because of increased flow.

3.11.4 Conclusions

- Due to changing management conditions, and other factors, a consistent BMP plan could not be implemented at this site and as a result, the assessment of BMP effectiveness could not be carried out.
- The use of portable windbreaks likely had little influence in attracting cattle away from the drainage channel in the field.
- Extractable soil N and P were not excessive at this site based on field-wide soil sampling. Fertilizer N, and in some years, fertilizer P are required for optimum crop growth.

Table 3.92. Annual nutrient and total suspended solids loads in runoff at the Reference site from 2008 to 2012.[z]

	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
Year[y]	------------------------------			($kg\ yr^{-1}$)				------------------------------
2008	2.65	1.53	1.03	0.06	0.99	0.89	0.09	6.33
2009	101	10.7	5.14	84.5	5.43	4.86	0.57	49.0
2012	3.64	0.86	2.77	0.0	0.11	0.06	0.04	23.9

[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.
[y] Load values were not available for 2010 and 2011 because of missin g flow data.

- The STP concentration in the drainage channel was much higher (101 mg kg^{-1}) compared to the whole field (22 mg kg^{-1}) in fall 2011. The STP results for the whole field suggest a relatively low risk of P loss. However, the STP results in the most hydrologically active area of the field (i.e., the drainage channel) showed a moderately high accumulation of P. The causes of higher STP concentrations in the channel are not clear. Reduced P uptake by crops under wet conditions and/or cattle access during fall grazing may be two possible factors.

- The application of commercial N and P resulted in measureable increases in extractable N and P in surface soil samples.

- On average, the majority (72%) of runoff was generated by rainfall during the 5-yr study period. Snowmelt runoff did not occur for 2 yr, and only dominated runoff in one year (2009).

- Although there was missing flow data at this site, it was estimated that the largest amount of runoff occurred in 2010 and 2011 due to above average precipitation, and this was consistent with data and observations elsewhere in the watershed.

- On average, the concentrations of NH_3-N, TP, TDP, and Cl were higher in snowmelt runoff; whereas, pH and concentrations of TN, ON, NO_3-N, PP, TSS, *E. coli*, and EC were higher in rainfall runoff.

- The majority of TN (72 and 76%) and TP (84 and 91%) were in dissolved forms in snowmelt and rainfall runoff, respectively. Generally, NH_3 was the dominant dissolved N form in snowmelt runoff; whereas, NO_3 was the dominant dissolved N form in rainfall runoff.

- There was evidence that the presence of cattle in the drainage channel likely had a negative effect of runoff water quality, particularly for N and *E. coli*.

- Average concentration of TP in runoff at the REF site (2.26 mg L^{-1}) was within the range of concentrations observed at the other edge-of-field BMP sites (1.17 to 2.62 mg L^{-1}) in the watershed. Whereas, the average concentration of TN in runoff at the REF site (24.8 mg L^{-1}) was higher than any of the other edge-of-field BMP sites (6.6 to 18.5 mg L^{-1}).

- Intensive tillage of adjacent native pasture in spring 2012 may have caused a large increase of TSS in runoff water from 29 mg L^{-1} (2008 to 2011 average) to an average of 702 mg L^{-1} in 2012.

3.12 Off-Stream Watering Site

3.12.1 Introduction and Hypotheses

The OSW site was one of four BMP sites selected late (2010) in the current study. The other three were the DUG, FLT, and CAT sites. The OSW site focused on riparian health and cattle management. Cattle at this site had direct access to water bodies including a dugout and IFC, which flowed through the site. The assumption was that the uncontrolled access of cattle to the dugout and the nearby creek caused riparian degradation, which in turn likely reduced water quality.

The BMP plan included preventing cattle access to the dugout and installation of an off-stream watering system. Because this site was established late in the study, a water-quality assessment could not be carried out to evaluate the effectiveness of the BMPs. However, other assessment tools were used including field observations, photographic recording, and riparian surveys. The hypothesis was:

- The implementation of no access to the dugout and use of an off-stream watering system would result in vegetation recovery around the dugout and in the riparian area at a nearby cattle access point on the creek.

3.12.2 Methods

3.12.2.1 Site Description and Management

The site was in the far northern part of IFC Watershed (Figure 3.4) and was within a farm management unit that was five quarter sections in size (Figure 3.118). Indianfarm Creek flowed through the farm from east to west and the site was 2.5 km from the watershed outlet. The farm was comprised of a farmyard and cattle facilities, native pasture on either side of IFC (about 110 ha), and crop land (about 200 ha). The cropland included fields for hay (crested wheatgrass/alfalfa or brome/alfalfa) and annual crop (barley and/or canola) production. The OWS site was located along the east side of the farmyard. The site included a dugout and the area between the dugout and IFC (Figure 3.119).

In 2010 and 2011, the management of cattle in the native pasture at the OSW site was connected to the IMP site (Sub-section 3.5). When cattle were not in the native pasture (Table 3.93), they were either in the corrals at the farmyard or on pasture at the IMP site. Cattle were allowed to graze all of the native pasture along IFC as well as fall graze adjacent annual cropland after harvest. Generally in late fall, calves and heifers were moved to the corrals and then sold. The herd was in the native pasture for about 155 d in 2010 and for about 159 d in 2011.

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3.12.2 Methods

3.12.2.1 Site Description and Management

The site was in the far northern part of IFC Watershed (Figure 3.4) and was within a farm management unit that was five quarter sections in size (Figure 3.118). Indianfarm Creek flowed through the farm from east to west and the site was 2.5 km from the watershed outlet. The farm was comprised of a farmyard and cattle facilities, native pasture on either side of IFC (about 110 ha), and crop land (about 200 ha). The cropland included fields for hay (crested wheatgrass/alfalfa or brome/alfalfa) and annual crop (barley and/or canola) production. The OWS site was located along the east side of the farmyard. The site included a dugout and the area between the dugout and IFC (Figure 3.119).

In 2010 and 2011, the management of cattle in the native pasture at the OSW site was connected to the IMP site (Sub-section 3.5). When cattle were not in the native pasture (Table 3.93), they were either in the corrals at the farmyard or on pasture at the IMP site. Cattle were allowed to graze all of the native pasture along IFC as well as fall graze adjacent annual cropland after harvest. Generally in late fall, calves and heifers were moved to the corrals and then sold. The herd was in the native pasture for about 155 d in 2010 and for about 159 d in 2011.

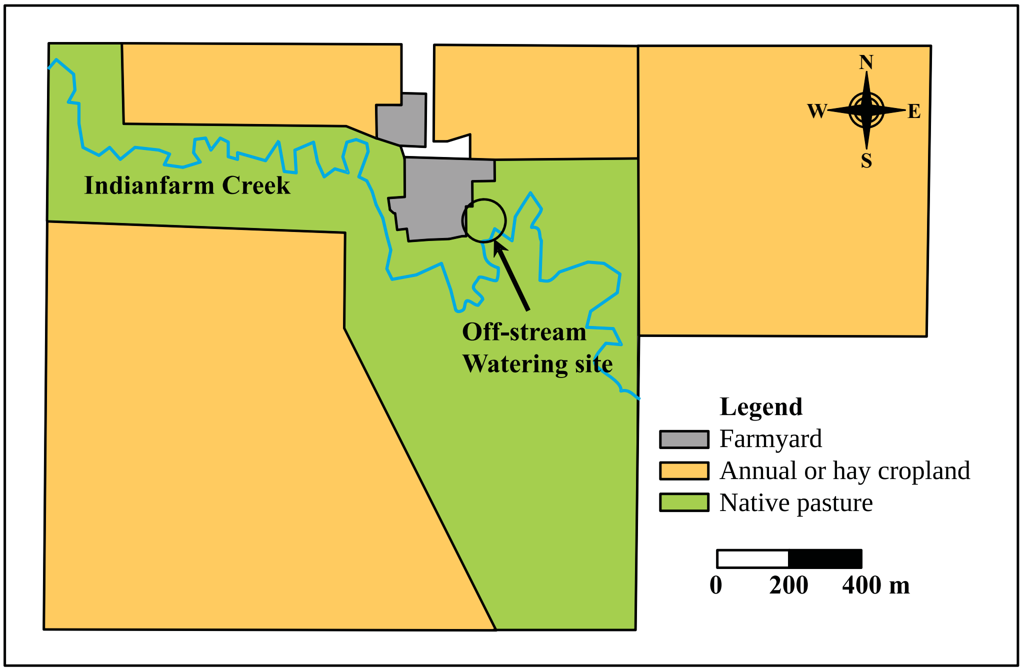

Figure 3.118. Location of the Off-stream Watering site within the five-quarter-section farm management unit.

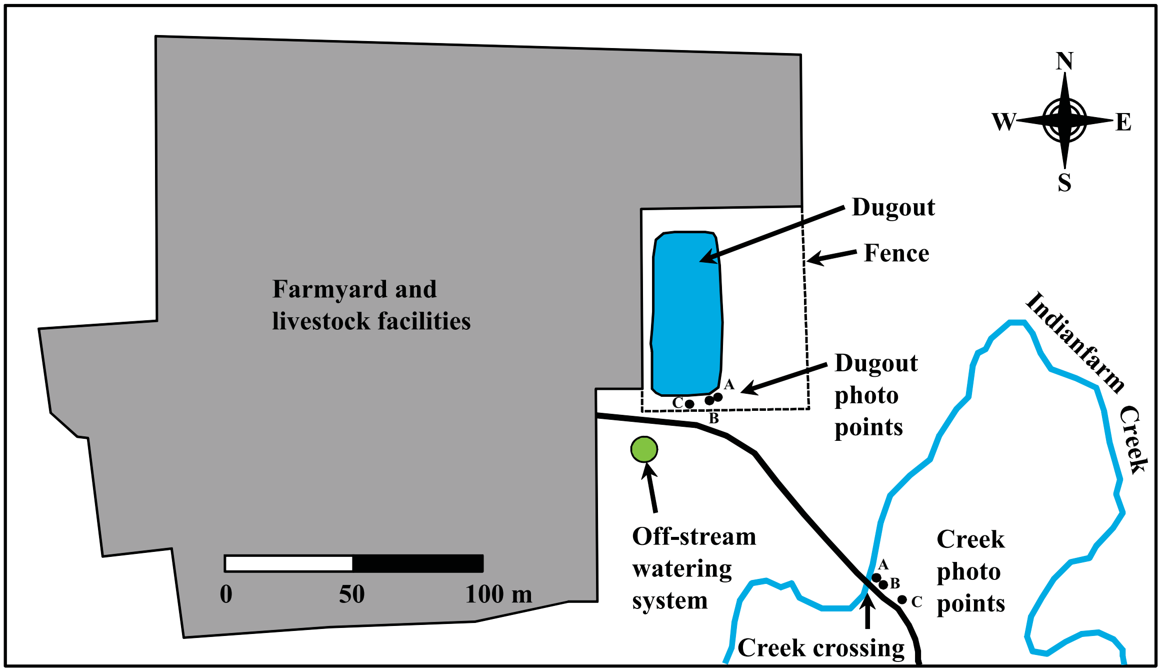

Figure 3.119. The location of the Off-stream Watering site relative to the farmyard, dugout, and Indianfarm Creek.

Table 3.93. Number of livestock and duration livestock were present in the native pasture at the Offstream Watering site from 2010 to 2012.

Dates on site	Livestock	Days on site[z]
	2010	
Apr. to Jun. 25	84 cow-calf pairs + 2 bulls	~86
Jul. 11 to 24	84 cow-calf pairs + 14 heifers + 3 bulls	13
Aug. 8 to Sep. 13	84 cow-calf pairs + 14 heifers + 3 bulls	36
Sep. 16 to Oct. 21[y]	84 cow-calf pairs + 14 heifers + 3 bulls	35
Oct. 29 to Nov. 7[y]	84 cow-calf pairs + 14 heifers + 3 bulls	9
Nov. 19 to 25[z]	84 cow-calf pairs + 14 heifers + 3 bulls	6
	2011	
May 1 to Jun. 22	87 cows-calf pairs + 2 bulls	52
Jul. 22 to Aug 18[x]	87 cows-calf pairs + 21 heifers + 3 bulls	27
Aug. 21 to Sep. 17[w]	87 cows-calf pairs + 21 heifers	27
Sep. 19 to Oct. 22[y]	87 cows-calf pairs + 21 heifers	33
Oct. 30 to Nov [y]	87 cows-calf pairs + 21 heifers	~20
	2012	
Jun. 1 to Jul. 14	80 cow-calf pairs + 20 heifers + 3 bulls	44
Jul. 15 to Aug. 14	80 cow-calf pairs + 20 heifers + 2 bulls	30
Aug. 15 to Nov [y]	80 cow-calf pairs + 20 heifers	~95

[z] The first and last days were assumed half days.
[y] Cattle also had access to adjacent cropland after harvest for fall grazing.
[x] Cattle were in corrals for 2 d during this period.
[w] Cattle were off site for 2 d during this period.

In 2012, the IMP site was no longer available as part of the grazing rotation. Prior to June 2012, 80 cow-calf pairs, 20 heifers, and 4 bulls were in the corrals at the farmyard. On June 1, 2012, 80 cow-calf pairs, 20 heifers, and 3 bulls (1 bull was left in the corrals) were moved onto the native pasture, where they remained for most of the remaining year (Table 3.93). It was estimated cattle spent about 170 d in the native pasture in 2012.

3.12.2.2 Implementation of Beneficial Management Practices

Cattle had direct access to IFC while they grazed the native pasture. The direct access to IFC had caused riparian degradation and stream bank erosion (Figure 3.120). As well, the fence around the dugout was in disrepair and cattle had direct access to the dugout for several years. The BMPs implemented at this site included repairing the dugout fence so cattle could no longer have access and the installation of an off-stream watering system.

The dugout was along the east side of the farmyard and it had a surface area of about 1600 m^2 (Figure 3.119). Wooden and loose barbwire fences surrounded the dugout; however, they were not effective in keeping cattle out. The fenced area was about 0.5 ha in size. The fence was fixed by restringing the barbwire.

The off-stream watering system was placed about 20 m south of the dugout, 23 m east of the nearest farm building, and about 100 m north of an access point on IFC (Figure 3.119). The off-stream watering system was placed at this location to attract cattle away from the access point on IFC (Figure 3.120b) and reduce the impact to the riparian area. The off-stream watering system included a concrete pad, a 2340-L trough, and wooden wind fence on the west side of the trough (Figure 3.121a). Water for the trough was supplied from the dugout through a pressure water line from an existing pump at the dugout (Figure 3.121b,c). Also, a cattle oiler was placed near the trough (Figure 3.121d) to help move the cattle out of the riparian area. The installation of the off-stream watering system and repairs to the dugout fence began in summer 2010 and were completed by mid-August 2010. In July 2012, a cattle feeder was placed a few metres south of the water trough, and the feeder was used to supply feed pellets.

3.12.2.3 Photo Points

Two photo-point locations were established at the OSW site based on protocols outlined by Delesalle et al. (2009). One photo point was at the south end of the dugout within the fenced area, and the other photo point was at the IFC access point about 100 m south of the off-stream watering system (Figure 3.119). The protocol involved using three pins placed in ground in a straight line at each location. Pin A marked the area that was photographed, and Pins B (2 m from Pin A) and C (10 m from Pin A) marked from where photographs were taken. A photo-point data sheet was used to record information including the photographer/observer, date, GPS coordinates, pin number, photo identification, BMP site, pin location, and comments.

Figure 3.120. Areas along Indianfarm Creek impacted by cattle access. The right image is of the access point and creek crossing, which is about 100 m south of the off-stream watering system.

Images were taken by first standing over Pin B and adjusting the camera zoom so the bottom of the image was 1 m in front of the photographer (i.e., halfway between Pins A and B) and the top of the image was about 0.3 m above Pin A. After taking this first image from Pin B, without adjusting the zoom and still standing at Pin B, a second image was taken so that Pin A was at the bottom of the image. A third image was taken from Pin C so that Pin A was in the middle of the image, again without adjusting the zoom. Photo-point images were taken on August 26, 2010; May 18, 2011; July 7, 2011; and July 17, 2012.

3.12.2.4 Riparian Quality

Riparian assessments were carried out to compliment the photo points, which were established at the OWS site (Figure 3.119). Eight, 1-m^2 quadrats (PVC-pipe frame) were assessed in total, with four quadrats at each photo-point location. At each photo point, representative locations were chosen to assess non-vegetated and vegetated areas (two quadrats each). The riparian assessments were completed on August 17, 2011 and on July 24, 2012. The variables recorded were plant species, species count, species cover, total bare ground, total litter, total moss, and total vegetation. The same quadrat locations were used in both years.

Figure 3.121. Images showing the (a) completed watering system and wind fence on October 7, 2010, (b) dugout pump shed, (c), water inlet to the trough, and (d) the cattle oiler.

3.12.3 Results and Discussion

3.12.3.1 Implementation of Beneficial Management Practices

The implementation of the BMPs in 2010 was straight forward and relatively easy to complete. Even though the fence around the dugout was repaired in 2010, some issues of cattle entering the dugout area continued in 2010 and 2011.The fence issue was eventually resolved and no cattle entered the dugout in 2012. The off-stream watering system and the cattle oiler worked very well at this site. It was observed that cattle often drank from the trough and used the oiler. It is, however, unknown whether the installation of the off-stream water system and oiler reduced the amount of time the cattle spent in the creek and riparian areas as they did still have access. When using the off-stream watering system, cattle would not have been at the creek, but cattle had access to the dugout prior to the installation of the off-stream watering system. Therefore, the new watering system may have replaced the dugout and perhaps the cattle did not spend any different amount of time at the creek. The collection of cattle distribution and behavior data would have been required in order to assess whether the off-stream watering system and oiler reduced the time cattle spent near the creek. However, it was anticipated that by excluding cattle from the dugout, water quality likely improved in the dugout and was a better source of water for the cattle.

The cost of the BMPs was slightly more than $4600 (Table 3.94). About 65% of this cost was for the cattle oiler.

3.12.3.2 Photo Points

Images taken in 2010 clearly showed the physical damage caused generally by the cattle at the dugout and creek access sites (Figures 3.122 to 3.124). The repaired fence was able to exclude the cattle from accessing the dugout and without cattle access, vegetation around the dugout was able to re-establish within 2 yr, with substantial growth by 2012 (Figure 3.122). In contrast, cattle still had access to IFC, and the images taken at the creek access point in 2011 and 2012 showed little change in vegetation recovery (Figures 3.123 and 3.124). There appeared to be some re-growth in 2012 (Figure 3.123).

Table 3.94. Cost of beneficial management practice implementation at the Off-stream Watering site.

Item	Material cost ($)	Labour (h)
Cement pad	771	5
Water trough, pipe, and fittings	598[z]	5
Wind fence	260[y]	5
Oiler	3012	0
Total	**4641**	**15**

[z] Pipe and fitting costs were estimated.
[y] Estimated.

Figure 3.122. Dugout photo-point images taken from Pin C at the Off-stream Watering site on August 26, 2010; July 7, 2011; and July 17, 2012.

Figure 3.123. Indianfarm Creek access area photo-point images taken from Pin B at the Off-stream Watering site on August 26, 2010; July 7, 2011; and July 17, 2012.

Figure 3.124. Indianfarm Creek access area photo-point images taken from Pin C at the Off-stream Watering site on August 26, 2010; July 7, 2011; and July 17, 2012.

3.12.3.3 Riparian Quality

At the IFC access site, the percent cover of litter and total vegetation increased and percent bare ground decreased from 2011 to 2012 for both quadrat types (Table 3.95). The increase in total vegetation and litter was more prominent for the non-vegetated quadrats. The increase in vegetation cover was mainly caused by grasses. Total percent grass cover increased from 2011 to 2012 in the non-vegetated and vegetated quadrats (Table 3.95). The dominant grass species were quack grass and Kentucky bluegrass; however, Kentucky bluegrass was not present in 2011. In contrast, percent cover of forbs decreased in 2012 from the previous year. The dominant forb species were field chickweed (*Cirsiumarvense*), western dock *(Rumex occidentalis)*, and gum weed *(Grindellia squarrosa*). Five of the forb species considered to be weeds were found in non-vegetated quadrats in 2011, but were not present in 2012. The percent cover of Canada thistle decreased in the vegetated quadrats and slightly increased in the non-vegetated quadrats from 2011 to 2012. This indicates there was still disturbance that occurred, and likely affected vegetation recovery.

The percent cover of shrubs (western snowberry and sand-bar willow) increased from 2011 to 2012, especially in the non-vegetated quadrats (Table 3.95). Western snowberry is not used by livestock for browsing and is not generally considered when evaluating riparian health, except for the root mass and vegetation cover (Ambrose et al. 2009). Willows are a preferred tree for browsing and will be the first shrubs species to disappear in a riparian area when it is over grazed. Therefore, the emergence of willows in 2012 was a positive sign for the recovery of this stretch on IFC.

Although the photo-point images showed little improvement from 2011 to 2012, the riparian survey results suggest that vegetation recovery did occur from 2011 to 2012, particularly in the growth of grasses. Additional time will be required to determine if this recovery continues and whether the off-stream watering system will have a long-term positive influence on riparian recovery at this location on the creek.

At the dugout non-vegetated quadrats, percent cover of total vegetation increased 2.3-fold, litter cover increased 5-fold, and bare ground decreased 2.7-fold from 2001 to 2012 (Table 3.95). The large reduction in bare ground cover is considered very positive in terms of recovery of the disturbed areas. An increase in percent litter cover from 8 to 40% was also very positive. Litter cover of 50% is the minimum required for a healthy riparian area. The same trends were also observed for the vegetated quadrats, however, to a lesser extent. Percent cover of grasses and forbs increased for both quadrat types. The dominant grass species were quack grass, Kentucky bluegrass, and downy brome (*Bromus tectorum*). The dominant forb species were knotgrass (*Polygonum aviculare*) and smartweed (*Polygonum lapathifolium*). There was also an increase in forb diversity from 2011 to 2012, with more aquatic species found in the non-vegetated quadrats. The strong increase in plant cover, shown by the riparian survey data, supports the visual changes recorded at the photo points (Figure 3.122).

A majority of dominant species at the dugout and IFC sites were non-native species. However, the presence of some desired species (e.g., western wheatgrass, yarrow, wild mint, and willows) was promising for further recovery at these sites. The non-native plants were invasive or disturbance species and these species are commonly present when an area is over grazed. However,

Table 3.95. Percent cover of grasses, forbs, shrubs, and other at the south pasture of the Off-stream Watering site.

		IFC 2011		IFC 2012		Dugout 2011		Dugout 2012	
		Non[z]	Veg	Non	Veg	Non	Veg	Non	Veg
		(%)							
		Grasses							
Hordeum jubatum	Foxtail barley		5		2.5	1		2.5	7.5
Bromus inermis	Smooth brome	2.5					20		
Agropyron repens	Quack grass	10	27.5	70	70	7.5	47.5	2.5	12.5
Beckmannia syzigachne	Slough grass		2.5						
Agropyron smithii	Western wheatgrass		6				10		
Bromus tectorum	Downy brome	2.50	2.5		6		10	2.5	45
Phleum pratense	Timothy							10	5
Poa pratensis	Kentucky bluegrass			5	22.5	1	7.5	10	40
Alopecurus aequalis	Water foxtail							6	
Agropyron dasystachyum	Northern wheatgrass						2.5		
Juncus (spp.)	Rush species							4.5	
Carex (spp.)	Sedge species							6	
	Total grasses	**15**	**44**	**75**	**101**	**10**	**98**	**44**	**110**
		Forbs							
Taraxacum officinale	Dandelion				0.5	1	1		
Potentilla anserina	Silverweed		5	0.5					
Cirsium arvense	Canada thistle	2	12.5	7.5	7.5			2.5	10
Achillea millefolium	Yarrow		5						
Rumex occidentalis	Western dock	5		1	5	2.5		1	
Plantago major	Common plantain		1.5	2.5	0	1.5		2.5	1
Grindellia squarrosa	Gumweed		12.5		2				
Geum Triflorum	Three-flower aven	7.5							
Epilobium ciliatum	Purple-leaved willowherb	1	1.5			0.5		6	2.5
Medicago lupulina	Black medick	0.5			2			2.5	3.5
Polygonum aviculare	Knotweed	1.5	1	0.5		20		15	20
Lappula echinata	Bluebur	0.5							
Chenopodium glaucum	Spare-leaf goosefoot	2.5				7.5		1	
Matricaria discoidea	Pineapple weed	0.5							
Thlaspi arvense	Stinkweed	0.5							
Polygonum lapathifolium	Pale smartweed					7.5	1	27.5	
Polygonum amphibium	Water knotweed					5			
Chenopodium album	Lamb's quarters					2.5			
Solidago canadensis	Goldenrod				3.5				
Cynoglossum officinale	Houndstongue							2.5	
Mentha arvensis	Wild mint								
Sonchus arvensis	Sowthistle							0.5	0.5
Ranunculus cymbalaria	Buttercup							1	
Sagittaria cuneata	Arrowhead							20	
Hieracium vulgatum	Hawkweed								7.5
Capsella bursa-pastoris	Shepherd's purse								1
Descurainia pinnata	Tansy							1	
Sagittaria subulata	Awl-leaved arrowhead							10	
	Total forbs	**22**	**39**	**12**	**21**	**48**	**2**	**93**	**46**
		Shrubs and other							
Symphoricarpos occidentalis	Snowberry	1.5	0.5	47.5	6				
Salix exigua	Sand-bar willow			1					
	Total litter	1	23	48	55	8	73	40	88
	Total bare ground	100	78	53	45	95	28	35	13
	Total moss	0	0	0	0	0	0	8	0
	Total vegetation	23	63	88	90	35	88	80	95

[z] Non = non-vegetative area, veg = vegetative area at the time of site selection (n = 2).

the percent cover of non-native species in the non-vegetated quadrats generally decreased from 2011 to 2012, with the exception of quack grass at the IFC site. The riparian health assessment results showed that both sites were unhealthy in 2011. Although the health ratings increased by 4 to 7% in 2012, the assessments still showed an overall unhealthy riparian area largely due to the invasive and disturbance species, which were dominant.

The results from the riparian survey showed that riparian recovery occurred at the dugout and IFC access sites. The recovery at the former site was more extensive than at the later site. Complete exclusion of cattle from the dugout area removed the pressures of grazing and physical disturbance, and this allowed plant recovery to begin quickly. Additional monitoring is required to confirm if recovery at IFC will continue, as it is expected that improvement will continue to a certain level as long as the BMPs are maintained.

3.12.4 Conclusions

- The areas around the dugout and at an access point along the IFC were heavily impacted by cattle.
- Riparian assessments showed that the dugout and IFC access areas were unhealthy. The BMPs were implemented in late summer 2010, and from 2011 to 2012, riparian health increased slightly by 4 to 7%.
- Cattle exclusion from the impacted area around the dugout using fencing resulted in a quick start to vegetation recovery.
- Some improvements were observed at the IFC access site, and these may be due to less access by cattle because of the nearby off-stream water system and cattle oiler. However, additional time is required to confirm this initial trend.

3.13 Dugout Site

3.13.1 Introduction and Hypotheses

The DUG site was one of four BMP sites established late (2010) in the study. As a result, water quality assessment of BMP effectiveness could not be carried out for this site within the remaining time of the study. This BMP site was a native pasture with a cow-calf operation. The main focus was on cattle access to water and the impact of cattle on riparian areas. The BMP plan included controlling access to dugouts, using off-stream watering, and improving creek crossings for cattle.

Even though water quality could not be assessed at this site, other assessment tools were used including field observations, photographic recording, and riparian survey. The assumption was that the uncontrolled access of cattle to dugouts and the creek caused riparian degradation, which reduced water quality. The hypothesis was:

- The implementation of controlled access to dugouts, off-stream watering, and improved creek crossings would improve riparian quality at the site.

3.13.2 Methods

3.13.2.1 Site Description and Management

The DUG site was about 11 km south of Pincher Creek and in the far southwest portion of IFC Watershed (Figure 3.3). The site consisted of wooded areas and native pasture with a variety of invader species. The pasture area was about 242 ha in size. Indianfarm Creek flowed through the site and was considered to be near the head waters of the watershed (Figure 3.125). The site was about 1 km downstream from Cridland Dam. In this part of the watershed, IFC was relatively narrow and shallow, compared to further north where the creek is wider and more incised. The site was in a low lying meadow, which was frequently wet. Historically, the meadow had been drained and alterations to the creek were evident. The site was divided by an east-west gravel road, with pasture land on the north and south sides of the road.

The north and south pastures had a supply of water from the creek, as well as one dugout and one artesian well in each pasture (Figure 3.125). The dugouts were constructed in close proximity to the creek with the south dugout directly linked to the creek (Figure 3.126a). There was a shallow channel between the north dugout and IFC (Figure 3.126b), and this channel would fill with water and connect to the dugout during periods of high flow in the creek.

Typically, more than 100 cow-calf pairs grazed the pasture and they were generally divided equally between the north and south pastures (Table 3.96). The cattle were moved to the pastures in early to mid-June and grazed throughout the summer and fall. In 2010, the herd size was 145 cow-calf pairs. The herd size was reduced to less than 100 cow-calf pairs in 2011 and 2012 in order to decrease the grazing pressure on the pastures.

3.14 Feedlot Site

3.14.1 Introduction and Hypotheses

The FLT site was a confined feeding operation adjacent to a tributary of IFC. The tributary flowed through a small seasonal feeding and bedding area adjacent to the feedlot pens. When in this area, cattle had direct access to the tributary. A dugout and a catch basin for the feedlot were also in the area. In some years, water flowing in the tributary would back-up and flood the catch basin and dugout. During flood events, the content of the catch basin would contaminate the dugout and water that flowed downstream to IFC. The BMPs included relocating the bedding and feeding area away from the tributary and constructing berms to protect the dugout and catch basin from flooding. Water quality at the FLT site was monitored using upstream and downstream stations on the tributary and IFC.

The assumption was that direct access by cattle to the tributary contributed nutrients and bacteria directly to the water and through runoff processes. Also, the degradation of pasture caused by cattle enhanced sediment loss through rainfall and snowmelt runoff. The hypothesis was:

- The relocation of the feeding and bedding area away from the tributary to prevent cattle access to the tributary would reduce the concentration of nutrients (N and P), sediment, and bacteria in the creek.
    - The removal of cattle would allow the recovery of the pasture along impacted reaches of the tributary.
    - Particulate nutrients were expected to be reduced more than dissolved nutrients because of improved ground cover from vegetation regrowth.

As a result of no flow at this site during the post year (2012), the hypothesis could not be tested using water quality data. Data from rangeland assessments and a photo point were used to determine pasture recovery in feeding and bedding area. Pre-BMP water quality data from the site, as well as IFC mainstem sites, were evaluated to determine the FLT tributary's effect on IFC.

3.14.2 Methods

3.14.2.1 Site Description and Management

The FLT site was in the northern part of IFC Watershed (Figures 3.3 and 3.4). The feedlot was a back-grounding operation and had a licensed capacity of 3000 animals. Immediately north of the feedlot pens was a seasonal feeding and bedding area (7.2 ha) used for cattle (Figure 3.134). A dugout (28 by 192 m) was within the feeding and bedding area and a catch basin (28 by 111 m) was along the north side of the feedlot pens. The dugout supplied water to the feedlot and the catch basin received runoff from the feedlot. The dugout was surrounded by a barb wire fence and the catch basin was surrounded by a wooden fence.

The seasonal feeding and bedding area was on a tributary of IFC (Figure 3.134). Water in the tributary flowed from east to west, draining the surrounding area (Figure 3.135). The area drained was about 1033 ha in size. Water in the tributary entered a settling pond and then drained into the dugout from the east side of the pond (Figure 3.136). During normal precipitation events, when the dugout reached full capacity, a drain on the west side of the dugout allowed overflow to continue down the tributary channel. The water flowed through culverts under the gravel road (Figure 3.137) and into IFC, which was about 370 m downstream from the culverts. The tributary generally flowed only in the spring.

In some years that had large precipitation events and/or rapid spring snowmelt, the two culverts under the gravel road on the west side of the feedlot could not handle the flow. As a result, water backed up and flooded the dugout, catch basin, and the seasonal feeding and bedding area. During flood events, the content of the catch basin contaminated the flood water, which entered the dugout and flowed downstream into IFC.

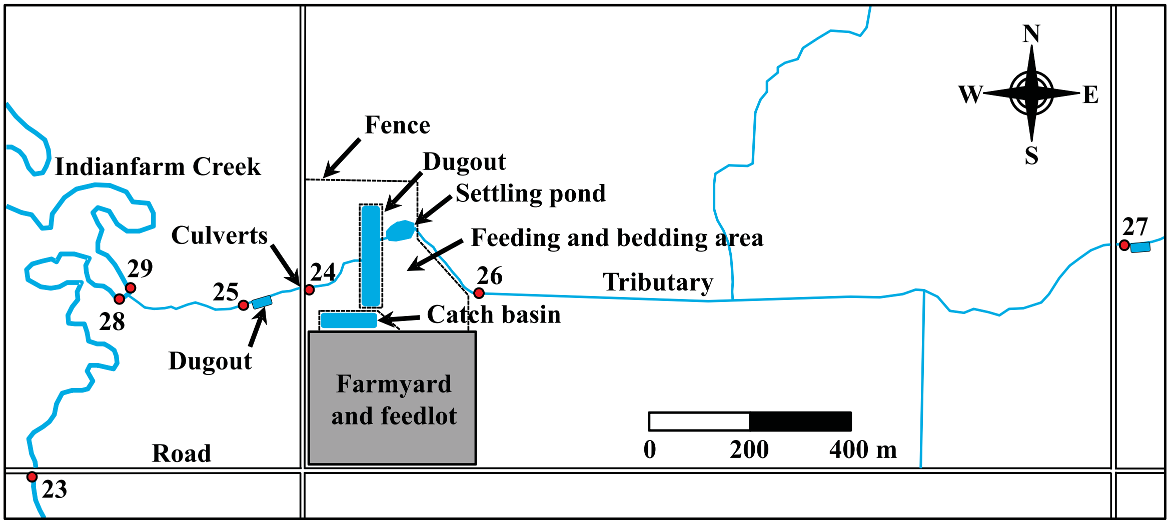

Figure 3.134. The Feedlot site showing the feeding and bedding area, dugout, catch basin, settling pond, tributary, and water monitoring Stations 24 to 29.

Figure 3.135. The tributary that flowed through the Feedlot site, as viewed upstream of Station 26 on June 2, 2010.

Figure 3.136. The settling pond (left) and the dugout (right) with the feedlot facility in the background on June 23, 2011.

The feedlot management activities were typical of a southern Alberta back-grounding operation. Cattle entered the feedlot weighing about 200 kg. After about 200 d, the cattle generally weighed about 385 kg and were typically moved to a finishing feedlot.

The seasonal feeding and bedding area generally received cattle in late December and occupied the site until mid-May. As many as 220 cow-calf pairs were fed in this area. When in the feeding and bedding area, cattle had direct access to the tributary. As a result, the area was heavily grazed, physically disturbed, and the tributary extensively impacted by the cattle (Figure 3.137).

Figure 3.137. Cattle in the tributary at the Feedlot site as viewed near Station 24 where water from the tributary flowed through culverts under the road. Image was taken on March 3, 2010.

3.14.2.2 Implementation of Beneficial Management Practices

The BMP plan consisted of two main parts: (1) construction of berms around the dugout and catch basin for flood protection and (2) relocation of the feeding and bedding area away from the tributary. In developing the BMP plan, approvals for various components of the plan were required from Alberta Environment and Sustainable Resource Development and the Natural Resources Conservation Board.

Prior to the construction of the berms, the site was surveyed by a contractor near the end of June 2011. The survey data were used to develop a topographic map of the area and the map was used to design the berms and trenches. The following were the main components of the construction project (Figure 3.138):

a. Add to the existing berms around the catch basin and dugout (Figure 3.139a-c).
b. Construct a diversion channel from the settling pond to the north (Figure 3.139d), around the dugout, and then south rejoining the tributary (Figure 3.139e) upstream from the road culverts.
c. Install sluice gates on the west and east berms of the dugout (Figure 3.139f).

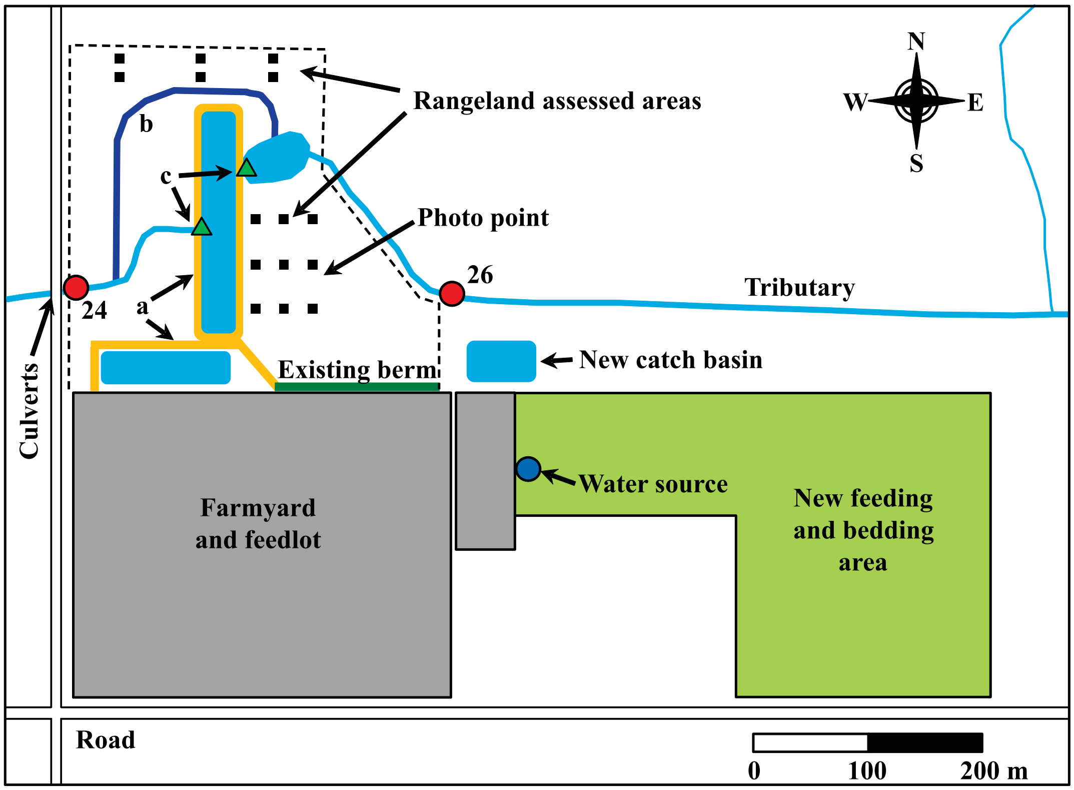

Figure 3.138. The Feedlot site showing the locations of (a) the constructed berms, (b) the new diversion channel, and (c) the sluice gates in the dugout. Also shown is the new feeding and bedding area.

Figure 3.139. Construction activities at the Feedlot site showing the new berms on the (a) west side and (b) east side of the dugout. Also showing (c) the berm on the north side of the catch basin, (d) the new diversion channel along the west side of the dugout, (e) the diversion channel exiting the north side of the settling pond, and (f) the sluice gate installed between the dugout and settling pond. Images were taken August 24 to September 12, 2011.

The construction of the berms began on August 24, 2011 using heavy earth-moving equipment and was completed in November 2011. Soil for the berms was obtained from an existing stock pile next to the dugout, the excavated diversion channel, and a newly constructed catch basin northeast of the feedlot. The tops of the completed berms were at the same elevation as the gravel road along the west side of the feedlot. If future flood water reached this elevation, the water will flow over the road and not over the berms. The barbwire fence surrounding the dugout and the wooden fence on the west, north, and east sides of the catch basin were removed prior to construction of the berms.

The feeding and bedding area was relocated east of the existing feedlot (Figure 3.138. The new area was about 7 ha in size. An underground water line was installed to provide water to the new area. An additional catch basin was excavated northwest of the new feeding and bedding area to receive the runoff from this area and prevent it from entering the tributary (Figure 3.140). The manure pack at the old feeding and bedding site was removed and incorporated into the manure management plan for the feedlot.

3.14.2.3 Photo Point

A photo point was located in the old feeding and bedding area about 80 m east of the dugout and about 80 m southeast of the settling pond (Figure 3.138). The photo-point procedures were based on protocols outlined by Delesalle et al. (2009). Three pins were secured to the ground. Pin A marked the area to be photographed. Pin B was 2 m from Pin A and Pin C was 10 m from Pin A and in line with Pin B. Details on how images were taken are described in Sub-section 3.12.2.3 for the OSW site. Images were taken on August 18, 2011 and on July 18, 2012.

3.14.2.4 Rangeland Assessment

To assess the recovery of vegetation in the old feeding and bedding area, rangeland assessment surveys were carried out. The surveys were carried out in two locations within the area: one north of the dugout and the other east of the dugout. The north location included six assessment points in a two-by-three grid (Figure 3.138). The two west and two middle points were in a 15- by 73-m arrangement. Because of a fence, the two east points were 63.4 m from the middle points. The east survey location included nine assessment points in a three-by-three grid. The points were separated by 25 m east-west and by 40 m north-south. The GPS coordinates of each assessment point was recorded. A 1-m^2 quadrat (PVC frame) was centered on each assessment point. For each quadrat, plant species, species count, species cover, and percent cover (bare ground, litter, and total vegetation) were recorded. Rangeland assessment surveys were carried out on July 27 and 28, 2011 and on July 25, 2012.

Figure 3.140. A new catch basin was established northeast of existing feedlot to receive runoff from the new feeding and bedding area. Image was taken October 21, 2011.

3.14.2.5 Water Flow and Quality

Four water monitoring stations were established in 2010 at the FLT site. Stations 24 and 25 were established first (Figure 3.134) in early March 2010. Stations 26 and 27 were established in early June 2010. Station 24 was on the tributary at the exit point from the FLT site on the east side of the gravel road and before the water entered the culverts (Figure 3.137). This station was considered the downstream station for the FLT site. Station 25 was further west on the tributary, immediately downstream of a small instream dugout (18 by 58 m), west of the road, and 75 m downstream from the culverts. This station evaluated the effect of the instream dugout on water quality before the tributary water entered IFC. Station 26 was located immediately upstream from the old feeding and bedding area and evaluated water before it entered the FLT site. This station was considered the upstream station for the FLT site. Station 27 was 1380 m further upstream from Station 26, on the east side of a township road and immediately downstream from another small instream dugout (20 by 55 m). Data from Site 27 are not presented, as this site was considered not relevant to assessing the impact of the FLT site on water quality in the tributary. A staff gauge was installed at each station. A Level TROLL was installed at Station 24 in 2012 (Sub-section 2.7).

Water samples were collected by grab sampling at Stations 24 to 27. The pre-BMP period was 2010 and 2011 and the post-BMP period was 2012. Stations 24 (downstream) and 26 (upstream) were the primary assessment stations for the FLT site. Unfortunately in 2012, only one sample was collected at Station 24 and no samples were collected at Station 26. As a result, the water quality data could not be used to evaluate the effectiveness of the BMPs.

Two additional stations (Stations 28 and 29) were added on the mainstem of IFC in late May 2011. Station 28 was immediately upstream of the tributary outlet and Station 29 was immediately downstream of the tributary outlet (Figure 3.134). Both sites were instrumented with staff gauges. The purpose of these sites was to evaluate of the effects of the FLT tributary on IFC water quality. Water samples were collected by grab sampling. The results from Stations 28 and 29 could only be compared to the tributary (Station 25) for one year (2011), as there was no flow from the tributary that reached IFC in 2012.

In addition to Stations 28 and 29, data from Station 12 at the WIN site (Figure 3.83) and Station 23 (Figure 3.134), were also used to determine the effects of the tributary on water quality in the mainstem of IFC. Station 12 was established in March 2007 and was about 2830 m downstream of the FLT tributary outlet. Station 23 was established in March 2010 and was about 1080 m upstream of the FLT tributary outlet. Statistical comparisons were carried out between the mainstem Stations 23 and 12 when the tributary flowed and when it did not flow from 2010 to 2012. Statistical comparisons were not carried out for Stations 28 and 29 because there were not enough samples (n = 5 or greater) and only one season of data was collected from both of these stations.

3.14.3 Results and Discussion

3.14.3.1 Implementation of Beneficial Management Practices

The BMP plan was successfully implemented in 2011. The main goal of moving cattle away from the tributary was achieved by relocating the seasonal feeding and bedding area. The new area was not operational for use in the 2011-2012 season because the watering system was not ready, and only a portion of the barbwire fence was constructed. The underground pipeline for the watering system was installed, but the rest of the system, such as a trough, was not installed. However, even though the new area could not receive cattle, cattle were kept off the tributary by using some empty feedlot pens and pasture south and east of the feedlot. The landowner did allow up to seven horses to graze the area on occasion during the post-BMP period.

Recovery of the area was observed quickly once the cattle were removed. Prior to the implementation of the BMPs, cattle typically used the feeding and bedding area in late fall, winter, and early spring. By spring, the area generally had very little vegetative cover (Figure 3.141a). The post-BMP seasons without cattle (2011-2012 and 2012-2013) resulted in good vegetation cover throughout the area (Figure 3.141b,c).

The construction of the new berms and channel allowed better management of the dugout water. During initial spring runoff, the two sluice gates were closed, ensuring the typically sediment-rich runoff water flowed through the settling pond, and around the dugout in the new diversion channel. Later, when the water turbidity had cleared, the east-berm sluice gate was opened and the dugout was filled with water. When the dugout became full, the west-berm sluice gate was opened and excess water flowed into the tributary.

The BMP plan included seeding the newly constructed dugout and catch-basin berms with grass seed. Due to delays caused by weather and other priorities, the berms were not seeded in 2011 or 2012 (Figure 3.142). However, vegetation established naturally on the berms and within 2 yr, they were completely covered. Much of the vegetation was weeds and although weed control may have

Figure 3.141. Surface conditions of the feeding and bedding area upstream from Station 24 in (a) the pre-BMP period (image taken on March 12, 2010) and in the post-BMP period on (b) March 12, 2012 and (c) May 13, 2013.

helped encourage the establishment of more grass, the established vegetation stabilized the berms and provided protection from erosion.

The total cost of the BMPs was $87,770, making this site one of the more expensive BMP sites in the study (Table 3.100). Nearly 40% of the cost was the construction of the berms, including the two sluice gates, trenching and excavation of the new catch basin. About 43% of the cost was the new feeding and bedding site, including fencing materials, the watering system, and access road.

3.14.3.2 Photo Point

Based on the images taken at the photo point, it was evident that vegetative growth was greater in 2012 compared to 2011 (Figures 3.143 and 3.144). Vegetative re-growth consisted of various grass species, such as crested wheatgrass (*Agropyron cristatum*), and weeds, such as field pennycress (*Thlaspi arvense*). This increase in vegetation was also supported by the rangeland assessments completed in 2011 and 2012.

Figure 3.142. Vegetation growth on the berm along the west side of the dugout at the Feedlot site on August 21, 2013.

Table 3.100. Cost of the implemented beneficial management practices at the Feedlot site.

Item	Material cost ($)	Labour (h)
Survey topography and design	5,000	20
Berms, trenching and new catch basin	35,000	30
Sluice gates and installation	10,000	16
New seasonal feeding and bedding site:		30
- Watering system	24,860	
- Fencing material and contract	3,730	
- New road to seasonal feeding and bedding site	9,180	
Total	**87,770**	**96**

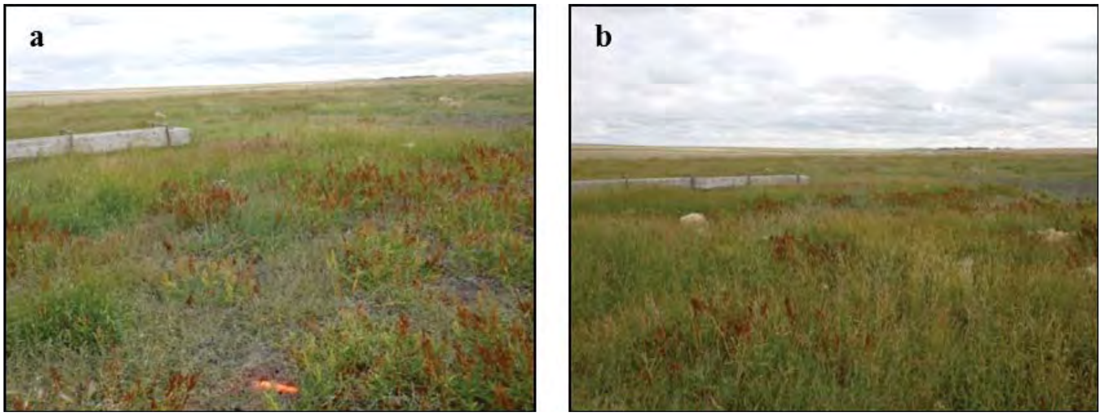

Figure 3.143. Photo-point images taken from (a) Pin B and (b) Pin C on July 2011. The orange colour shows the location of Pin A.

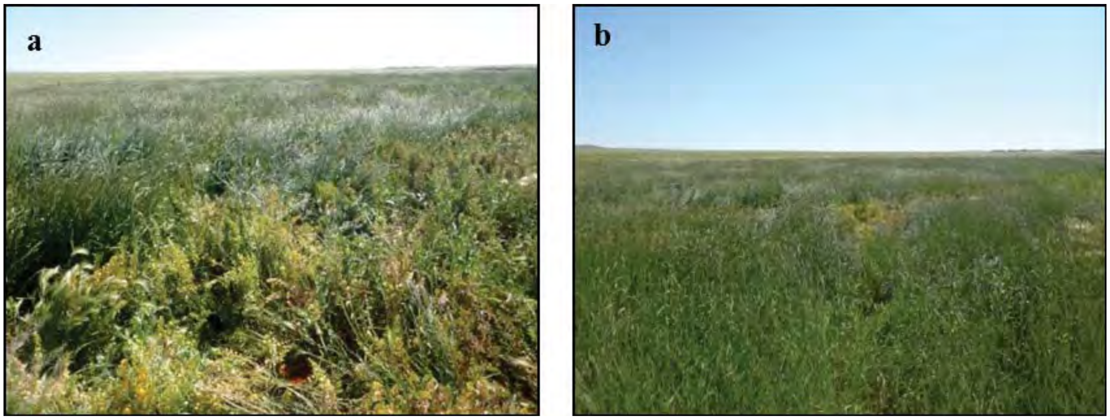

Figure 3.144. Photo-point images taken from (a) Pin B and (b) Pin C on July 18, 2012. The orange colour shows the location of Pin A.

3.14.3.3 Rangeland Assessment

At the north and east (relative to the dugout) assessment areas (Figure 3.138), percent cover of total vegetation increased 1.5- to 2-fold, litter increased 9-fold, and bare ground decreased about 2-fold from 2011 to 2012 (Tables 3.101 and 3.102). The low percent cover of litter (6 to 8%) and the higher percent cover of bare ground (72 to 85%) in 2011 were indicative of an unhealthy pasture. Most of the vegetation increase in the north area was due to grasses; whereas, grasses and forbs contributed to the increase in total vegetation in the east area. The increase in vegetation and litter showed that removing the grazing pressure and physical disturbance of cattle in this pasture positively affected pasture recovery. This was also supported by the images taken at the photo point, which was near the east rangeland assessment area (Figure 3.138).

Table 3.101. Percent cover of grass, forb, litter, and other at the north rangeland assessment area in 2011 and 2012.

		Percent cover[z]		Grazing	Forage
		2011	2012	response[y]	value[x]
		Grass species			
Poa pratensis	Kentucky bluegrass	0.8	15.0	EIV	G
Hordeum jubatum	Foxtail barley	12.2	8.3	IV	P
Agropyron repens	Quack grass	43.3	54.2	EIV	G
Agropyron smithii	Western wheatgrass	5.8	30.0	I	G
Carex sp.	Sedge	0.2		D	G
Bromus inermis	Smooth brome		15.0	EIV	G
Agropyron subsecundum	Awned wheatgrass		0.3	D	G
	Total Grasses	**62.3**	**122.8**		
		Forb species			
Aster laevis	Smooth aster	0.8	4.2	I	F
Rumex occidentalis	Western dock	2.0		EIV-IV	P
Taraxacum officinale	Dandelion	0.2	0.7	EIV	F
Chenopodium glaucum	Lambsquarters	0.3	1.0	EIV	P
Thlapsi arvense	Stinkweed	0.7		I	P
Polygonum aviculare	Knotweed	1.7	0.7	EIV	P
Capsella bursa-pastoris	Shepherds purse		3.5	EIV	P
Polygonum convolvulus	Wild buckwheat		0.2	EIV	F
	Total Forbs	**5.7**	**10.2**		
		Other			
	Total litter	8	72		
	Total bare ground	72	28		
	Total vegetation	65	97		

[z] Each value is an average for six quadrats (n =6).
[y] Grazing response: D = decreaser, I = increaser, IV = invader, EIV = exotic invader.
[x] Forage value: G = good, F = fair, P = poor, Pois = poisonous.

Table 3.102. Percent cover of grass, forb, and other at the east rangeland assessment area in 2011 and 2012.

		Percent cover[z] 2011	Percent cover[z] 2012	Grazing response[x]	Forage value[y]
		Grass species			
Agropyron repens	Quackgrass	21.2	36.1	EIV	G
Hordeum jubatum	Foxtail barley	7.1	28.1	IV	P
Agropyron smithii	Western wheatgrass		3.6	I	G
Beckmannia syzigachne	Slough grass		1.7	I	G
Bromus inermis	Smooth brome		0.1	EIV	G
Avena fatua	Wild oat		0.6	D	G
	Total Grasses	**28**	**70.1**		
		Forb species			
Rumex occidentalis	Dock	0.9	5.7	EIV-IV	P
Cirsium arvense	Canada thistle	0.1	1.2	IV	P
Polygonum aviculare	Knotweed	20.3	29.7	EIV	P
Chenopodium album	Lambsquarters	0.2	4.8	EIV	P
Capsella bursa-pastoris	Shepherds purse		20.1	EIV	P
Polygonum convolvulus	Wild buckwheat		0.2	EIV	F
Chenopodium glaucum	Spare-leaf goosefoot		0.1	EIV	P
Polygonum lapathifolium	Smartweed		0.2	I	P
Sonchus arvensis	Sowthistle		0.1	EIV	F
Descurainia sophia	Flixweed		1.8	EIV	P
	Total Forbs	**21.6**	**63.9**		
		Other			
	Total litter	6	56		
	Total bare ground	85	44		
	Total vegetation	47	96		

[z] Each value is an average for nine quadrats (n =9).
[x] Grazing response: D = decreaser, I = increaser, IV = invader, EIV = exotic invader.
[y] Forage value: G = good, F = fair, P = poor, Pois = poisonous.

The dominant grass species at the north area were quack grass and western wheatgrass in 2012 (Table 3.101). The dominant forb species were smooth aster (*Aster laevis*) and shepherds purse (*Capsella bursa-pastoris*). Two new grass species and two new forb species were found in 2012, and two forb species found in 2011 were not observed in 2012.

The dominant grass species at the east pasture were quack grass and foxtail barley, and the dominant forb species were knotweed and shepherds purse in 2012 (Table 3.102). Four new grass species and six new forb species were found in 2012. The majority of the forb species at this pasture were considered to be non-native, invasive weeds and do not provide good forage value.

The invasive vegetation did, however, help improve the vegetative cover, reduced the bare ground and increased the litter, which all helped to protect the site from erosion by wind and water.

Even though percent vegetation and litter cover increased, the old feeding and bedding area substantially lacked native species, meaning species diversity was low. The area was extremely modified from a native state and recovery to the reference plant community for the Foothills Fescue ecological subregion is very unlikely. However, recovery to a healthy tame pasture is possible. The east assessment area was in poorer condition than the north area. Practices that could be used to improve the forage value of the east area include spraying weeds, re-seeding with a reclamation or tame seed mixture, and continuing the rest from grazing. The north area should continue to recover on its own with continued rest or with some rotational grazing management during less sensitive times of the year.

3.14.3.4 Water Flow and Quality

Water flow. Flow through the tributary in spring 2010 and 2011 (Figure 3.145) was generated by snowmelt and rainfall. Instantaneous flow at Station 24, as calculated from staff gauge readings during water sampling, peaked at 2.2 $m^3 s^{-1}$ in 2010 and at 1.4 $m^3 s^{-1}$ in 2011. Flow at Station 26 was always less than Station 24. The sites were not instrumented to collect continuous flow data in the pre-BMP years (i.e., Level TROLL was not installed at Station 24 until 2012) and essentially no measurable flow occurred in 2012 (post-BMP). Station 24 flowed once in 2012, but there was insufficient flow metering data to determine flow values. Visual observations and field notes indicated flow was minimal.

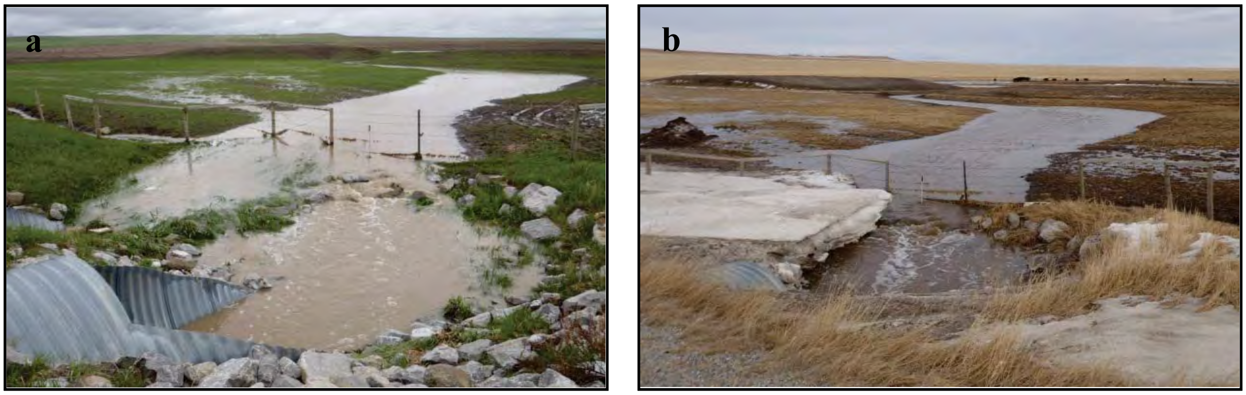

Figure 3.145. Water flow from the Feedlot site at Station 24 on (a) May 31, 2010 and on (b) March 15, 2011.

Water quality. The concentration of TN was relatively consistent with time in 2010 and 2011 at the upstream (Station 26) and downstream (Station 24) stations at the FLT site (Figure 3.146a). However, there were a few higher TN concentration peaks in 2011, and these were higher than any peak concentrations in 2010. A wet growing season and fall in 2010, and the largest snowmelt period of the study in 2011 (Sub-section 3.4.2.1) may have contributed to the peak TN concentrations in 2011. Increased losses of TN and dissolved inorganic N during extended wet periods has been reported in other studies (Donner et al. 2004; Donner and Scavia 2007; Nangia et al. 2010). Total P concentrations in 2010 and 2011 (from late March to mid May 2011) and PP concentration in 2010 generally decreased with time, though TP peaks occurred in late May and June 2011 (Figure 3.146b,c). In 2011, PP concentration was variable, but there was no consistent trend with time. Total P peaked at the onset of snowmelt in March 2011 and again during rainfall events in late May and early June 2011 (Figure 3.146b). Higher peak concentrations of TSS and *E. coli* were observed in 2011 compared to 2010 (Figure 3.146d,e). In 2011, the concentration of TSS and *E. coli* generally increased with time at the downstream station (Station 24).

For most of the water quality parameters, average concentration was higher during rainfall runoff compared to snowmelt runoff at Stations 26 (upstream) and 24 (downstream). The largest upstream-downstream difference was for *E. coli* concentration, which was over 8-fold greater at Station 24 during rainfall runoff (Table 3.103). In contrast, Cl at both stations and ON and NH_3-N at Station 24 had lower concentrations in rainfall events compared to snowmelt events. Average pH values were the same for the two event types.

For all events (snowmelt and rainfall) on average, nearly 60% of TN was in dissolved inorganic forms (NO_3-N+NH_3-N), and 74 to 83% of TP was TDP at Stations 24 and 26, respectively (Table 3.103). The proportion of dissolved nutrients was higher than the values reported for the mainstem of IFC in the watershed-wide assessment (Sub-section 3.4.2.2). This is consistent with other tributaries in the IFC Watershed, where tributaries typically had a higher proportion of TN and TP in dissolved forms compared to the mainstem (Sub-section 3.4.2.2). For the FLT site tributary, TDP was dominant during snowmelt and rainfall runoff events (Table 3.103). Total N was also dominated by dissolved forms (NO_3-N plus NH_3-N) during rainfall events; however, TN was marginally dominated by ON during snowmelt.

During snowmelt events, the average concentrations of NH_3-N, PP, TSS, and *E. coli* were significantly (P <0.1) higher downstream compared to upstream, with increases ranging from 1.8- to 6.9-fold (Table 3.103). The snowmelt average concentrations for TN, ON, and NO_3-N were also higher at the downstream station, but were not statically different from the upstream station. The remaining parameters had concentration that were similar between the two stations (TP, EC, pH) or had lower values at the downstream station compared to the upstream station (TDP and Cl). The increase in PP concentration was likely associated with the increase in TSS concentration. The reason why TP did not change between the two stations is because the increase in PP concentration from upstream to downstream was offset by a decrease in TDP concentration, which accounted for more than 74% of the TP during snowmelt. These results show that the feeding and bedding area contributed to water quality deterioration, particularly for PP, TSS, and *E. coli* during snowmelt.

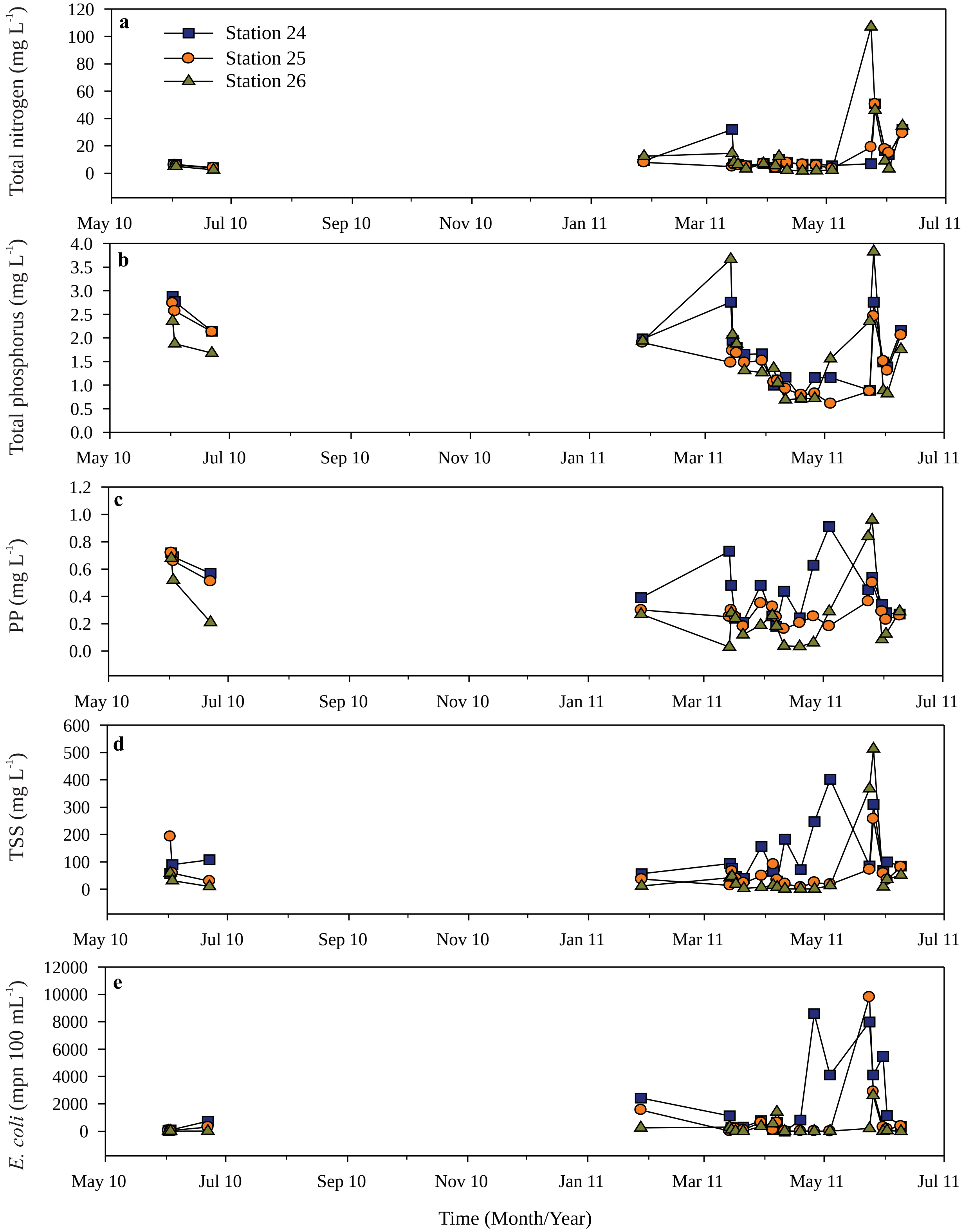

Figure 3.146. Concentrations of (a) total nitrogen; (b) total phosphorus; (c) particulate phosphorus (PP); (d) total suspended solids (TSS), and (e) *Escherichia coli* (*E. coli*) measured at Stations 24, 25, and 26 at the Feedlot site from June 2010 to June 2011.

Table 3.103. Average concentrations for runoff water quality parameters measured during snowmelt and rainfall runoff at upstream station (26) and downstream station (24) on the Feedlot tributary from June 2010 to June 2011.[z]

Station[y]	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli* (mpn 100 mL^{-1})	EC ($\mu S\ cm^{-1}$)	pH
	(mg L^{-1})											
					Snowmelt (n = 11)[x]							
26 (upstream)	6.90	3.54	2.39	0.79*b*	1.52	1.36	0.15*b*	14*b*	24.9	272*b*	380	7.66
24 (downstream)	9.30	5.17	2.60	1.43*a*	1.54	1.15	0.39*a*	97*a*	22.6	1388*a*	362	7.71
					Rainfall (n = 9)							
26 (upstream)	23.9	9.49	12.9	1.39	1.90	1.46	0.44	122*b*	13.1	322*b*	458	7.96
24 (downstream)	15.8	4.67	9.94	1.11	1.96	1.43	0.53	145*a*	13.7	2669*a*	405	8.04
					All events (n = 20)							
26 (upstream)	14.6	6.22	7.12	1.06*b*	1.69	1.40	0.29	62.7*b*	19.6	294*b*	415	7.80
24 (downstream)	12.2	4.94	5.90	1.29*a*	1.73	1.28	0.45	119*a*	18.6	1965*a*	381	7.86

[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, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.

[y] Average values were calculated using data from dates that both sites were sampled. Therefore, the data for Station 24 before Station 26 was established (i.e., prior to June 2010) were not used for this comparison.

[x] Averages per parameter and event type followed by letters are significantly different at $P < 0.1$.

During rainfall events, the concentration of TSS and *E. coli* significantly (P <0.1) increased by 1.2-fold and 8.3-fold, respectively, from upstream to downstream (Table 3.103). The concentration of PP was also higher at the downstream station, but was not statically different from the upstream station. The concentrations of the remaining parameters were similar between the two stations (TP, TDP, Cl, and pH) or decreased from upstream to downstream (TN, ON, NO_3-N, NH_3-N, and EC). However, the concentration values that decreased at the downstream station were not statistically different from the upstream station. Compared to snowmelt events, rainfall events had less effect on water quality at the FLT site in terms of the number of parameters that increased in concentration from upstream to downstream and the magnitude of the increases.

For all events (snowmelt and rainfall), the concentration of NH_3-N, TSS, and *E. coli* were significantly (P <0.1) increased from upstream to downstream (Table 3.103). The largest increase was for *E. coli*, which increased by 6.7-fold. The concentration for PP was higher at the downstream station, but was not significantly different from the upstream station. The remaining parameters were either similar or lower at the downstream station compared to the upstream station; however, the decreased concentrations at the downstream station were not statistically significant from the upstream station. These results suggest that the main effect of the FLT site on water quality degradation was from TSS and *E. coli*, and PP was likely associated with TSS. It would appear that the loss of nutrients, particularly dissolved nutrients, may not be the main concern at the FLT site. The feeding and bedding site was relatively small (7.2 ha) compared to drainage area of the tributary (1033 ha), and the site was near the outlet of the tributary. Therefore, the amount of runoff from this site was likely small compared to the contribution from upstream of Station 26. However, with manure accumulation and the highly degraded ground surface in the feeding and bedding area caused by cattle resulted in measureable increases in TSS and *E. coli* in the tributary from Station 26 to Station 24.

The instream dugout immediately downstream of Station 24 had a significant effect on some water quality parameters. The average concentrations of PP, TSS, and *E. coli* for all events were significantly reduced from Station 24 to Station 25 (Table 3.104). Several other parameters (TN, ON, NH_3-N, TP, and Cl) had lower average concentrations (8 to 24%) at Station 25, but were not significantly different from Station 24. For the remaining parameters (NO_3-N, TDP, EC, and pH), average concentrations for all events varied little between the two stations.

The largest change due to the dugout occurred for TSS concentration, which decreased by 87% for all events from upstream to downstream (Table 3.104). The TSS concentration was significantly reduced in snowmelt and rainfall events, while PP and *E. coli* concentrations were significantly reduced during snowmelt and all events at the downstream station. The TSS concentration decrease likely influenced the relatively large decreases (53 and 65%, respectively) in PP and *E. coli* concentrations. Station 25 was about 200 m downstream from Station 24 and at the outlet of the instream dugout. The instream dugout between the two stations improved water quality, particularly for those parameters associated with sediment, which likely settled in the dugout. However, the quality of water exiting the dugout was still of concern as water from the dugout entered IFC about 190 m further downstream (Figure 3.134).

As previously indicated, pre- and post-BMP data could not be compared statistically because of a lack of samples in the post-BMP year (2012). However, one sample was collected on June 27, 2012 at Station 24. The concentrations of TN (3.47 mg L^{-1}) and NO_3-N (0.025 mg L^{-1}) were less than the minimum values for TN (4.07 mg L^{-1}) and NO_3-N (0.23 mg L^{-1}) observed during the pre-BMP period (2010 and 2011). The values for the other parameters in the single 2012 sample were within the ranges observed in 2010 and 2011, although the 2012 sample values were towards the low end of the ranges. This may suggest an improvement due to the BMP; however, one sample is not enough to make this determination, and additional samples are required for more than one year in order determine whether or not the BMP is effective regarding the improvement of water quality.

Table 3.104. Average concentrations for runoff water quality parameters measured during snowmelt and rainfall runoff at Stations 24 and 25 at the Feedlot site from March 1, 2010 to June 27, 2012. [z]

Station	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli*	EC	pH
	(mg L^{-1})									(mpn 100 mL^{-1})	(µS cm^{-1})	
Snowmelt (n = 18) [y]												
24	9.13	5.64	1.88	1.53	2.54	1.44	1.10*a*	950*a*	23.5	4646*a*	382	7.75
25	6.94	3.91	1.83	1.12	1.82	1.49	0.33*b*	49*b*	23.5	274*b*	373	7.73
Rainfall (n = 22)												
24	16.3	3.74	11.5	0.87	1.93	1.45	0.48	204*a*	15.7	2434	414	8.00
25	16.3	3.47	12.0	0.70	1.77	1.38	0.39	88*b*	13.0	1950	410	8.01
All events (n = 40)												
24	13.1	4.59	7.19	1.17	2.21	1.44	0.76*a*	540*a*	19.2	3430*a*	400	7.89
25	12.1	3.67	7.43	0.89	1.80	1.43	0.36*b*	70*b*	17.7	1196*b*	394	7.88

[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, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Averages per parameter and event type followed by letters are significantly different at $P < 0.1$.

Even though some of the parameters were attenuated by the dugout downstream from Station 24, the concentration of most parameters at Station 25 (Table 3.104) were still several fold greater than at Station 23 and Station 12 on the mainstem of IFC when the tributary was flowing (Table 3.105). For example, the overall average concentration of TN was 4.7-fold, TP was 3.5-fold, and *E. coli* was 2.4 fold greater at Station 25 compared to Station 23 when the FLT tributary was flowing (Tables 3.104 and 3.105). These results were consistent with other comparisons of edge-of-field and small tributary water quality values with the mainstem of IFC. One notable exception at the FLT site was TSS concentration, which was about 5-fold less at Station 25 than at Station 23, and this decrease in TSS concentration was likely due to the settling of sediment in the dugout prior to reaching IFC.

During the periods when the FLT tributary flowed in 2010 and 2011, nearly all water quality parameter concentrations increased from upstream (Stations 23) to downstream (Station 12) in the mainstem of IFC (Table 3.105). However, the only parameter that was significantly higher at the downstream station was Cl. As highlighted in the watershed-wide assessment (Sub-section 3.4), the concentration of water quality parameters generally increased from upstream to downstream in IFC, and this was the case for the reach between Stations 23 and 12. When the FLT tributary was not flowing, the parameter concentrations between Stations 23 and 12 were not as large, and more parameters (NO_3-N, NH_3-N, *E. coli*, and EC) had less concentration at the downstream station. These results suggest that the FLT tributary had a measureable impact on IFC by increasing the concentration of several water quality parameters.

Stations 28 and 29 were immediately upstream and downstream, respectively, from the FLT tributary outlet. The results from these two stations in 2011 confirmed a measurable impact of the FLT tributary on IFC. Similar to the IFC stretch between Stations 23 and 12, nearly all water quality parameters had larger average concentration at the downstream station compared to the upstream station when the tributary was flowing into IFC (Table 3.106). Among parameters that did not increase included PP and TSS. These two parameters were lower in concentration at Station 25 (rainfall, snowmelt, and all events) compared to Station 28 when the tributary was flowing. Therefore, it is likely that the tributary had a dilution effect in 2011 on IFC by contributing better quality water with regard to these parameters. When the tributary was not flowing, the parameter concentrations were similar between Stations 28 and 29 (Table 3.106).

The ability to measure an impact of the FLT tributary on IFC may vary. During the high-flow synoptic survey carried out on May 26, 2008, Site N (i.e., the FLT tributary) was isolated using upstream Site M (i.e., Station 28) and downstream Site O (i.e., Station 29) (Sub-section 3.4). The survey showed that the FLT tributary had little influence on water quality in IFC, based on a one-time sampling. For example, TP concentrations at Sites M and O were 0.38 and 0.37 mg mL^{-1}, respectively; whereas, the concentration at Site N was 0.59 mg mL^{-1}. Flow at Site N was 0.2% of the flow at Site M on IFC at the time of the synoptic survey in May 2008. The flow data collected in 2010 and 2011 indicated that the FLT tributary flow was generally less than 4%, but occasionally ranged from 18 to 43% of creek flow at Site 12. It is probable that the FLT tributary had a larger impact on water quality in IFC during the high-flow events that were captured in 2010 and 2011 compared to the synoptic survey event in May 2008.

Table 3.105. Average concentrations of water quality parameters at Stations 12 and 23 when the Feedlot tributary was flowing and not flowing in from 2010 to 2012.[z]

Station	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	E. coli (mpn 100 mL^{-1})	EC (µS cm^{-1})	pH
	(mg L^{-1})											
During tributary flow (n = 36)[y]												
23 (upstream)	2.58	1.52	0.81	0.21	0.52	0.17	0.35	332	7.08*b*	491	481	8.25
12 (downstream)	3.60	1.88	1.39	0.29	0.87	0.28	0.59	449	7.90*a*	730	470	8.23
During no tributary flow (n = 31)[x]												
23 (upstream)	1.10	0.78	0.27	0.04	0.02	0.08	0.10	43	5.68	909*a*[w]	618	8.30
12 (downstream)	1.15	1.00	0.12	0.03	0.03	0.09	0.12	47	5.71	87*b*	595	8.30

[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 suspen ded solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Averages per parameter and event type followed by letters are significantly different at $P < 0.1$.
[x] The FLT tributary flow on June 27, 2012 was minimal and no sample could be collected from the upstream station (26) on the tributary, so samples collected on this day were included with the no tributary flow samples.
[w] This high average and difference is because of a high *E. coli* count on July 12, 2011 (19,863 mpn 100 mL^{-1}) that was not detected further downstream at Station 12 (20 mpn 100 mL^{-1}).

Table 3.106. Average concentrations of water quality parameters at Stations 28 and 29 when the Feedlot tributary was flowing and not flowing during rainfall runoff in 2011.[z]

Station	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	E. coli (mpn 100 mL^{-1})	EC (µS cm^{-1})	pH
	(mg L^{-1})											
During tributary flow (n = 5)[y]												
28 (upstream)	3.42	2.12	1.08	0.21	0.99	0.19	0.80	838	4.68	1578	434	8.23
29 (downstream)	8.78	2.24	5.88	0.60	1.06	0.42	0.64	645	7.56	1886	455	8.21
During no tributary flow (n = 4)												
28 (upstream)	1.44	1.17	0.23	0.03	0.15	0.05	0.10	58	6.79	452	672	8.31
29 (downstream)	1.40	1.14	0.22	0.03	0.15	0.05	0.10	63	6.34	439	667	8.32

[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, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Averages per parameter and event type followed by letters are significantly different at $P < 0.1$.

The FLT site illustrated the difficulties in evaluating the effectiveness of BMPs on water quality. The BMPs at this site were designed to address two issues: the impact of cattle on a tributary and the flooding of the feedlot catch basin. The cattle were removed and berms were constructed to protect the catch basin from floods. The pre-BMP data collected in 2010 and 2011 represented only the impact of cattle because the catch basin was not flooded during this period. Therefore, post-BMP data should only include the exclusion of cattle. If in the future the tributary should back-up and flood the old feeding and bedding site, and not flood the catch basin because of the new berms, a comparison cannot be made because pre-BMP data under flood conditions were not obtained.

3.14.4 Conclusions

- The exclusion of cattle from the feeding and bedding area resulted in rapid vegetation recovery and the ground surface was better protected adjacent to the tributary. However, the vegetation recovery lacked native pasture species. It was suggested that a tame pasture seed mixture should be planted in areas of high disturbance and efforts (e.g., spraying weeds and continued cattle exclusion) made to encourage pasture recovery towards a healthy tame pasture community.

- The average concentration of most of the water quality parameters was higher during rainfall runoff compared to snowmelt runoff at the upstream (Station 26) and downstream (Station 24) stations, except for Cl and pH at both stations and ON and NH_3-N at Station 24.

- On average, the majority of TN (nearly 60%) and TP (74 to 83%) were in dissolved forms. These proportions were higher compared to the IFC mainstem, and this was consistent with other tributaries in the IFC Watershed.

- Two years (2010 and 2011) of monitoring prior to BMP implementation showed that for all events (snowmelt plus rainfall), the concentrations of NH_3-N, TSS, and *E. coli* were significantly ($P < 0.1$) increased from upstream (Station 26) to downstream (Station 24). The loss of nutrients, particularly dissolved nutrients, may not be the main concern at the FLT site, but rather TSS, PP, and *E. coli*.

- The loss of PP, TSS, and *E. coli* was likely due to extensive surface disturbance caused by the cattle and the presences of fecal pats near and in the tributary.

- The presence of a small instream dugout immediately downstream of the FLT site caused significant reductions in the concentrations of PP, TSS, and *E. coli*. The concentration of TSS was decreased by 87%, and this likely influenced the 53% decrease in PP and the 65% decrease in *E. coli* concentrations. In contrast, NO_3-N and TDP concentrations were not affected by the dugout. The dugout acted as a settling pond for sediment materials and associated nutrients and bacteria.

- The average concentrations of N parameters, TP, TDP, Cl, and *E. coli* were greater in the FLT tributary (Station 25) for all events (snowmelt and rainfall) compared to Stations 23 and 12 on the mainstem of IFC, although Cl was the only parameter that was significantly higher. In contrast, PP, TSS, and EC concentrations were either similar or lower in the tributary compared to the IFC mainstem during runoff events.

- Results from the monitoring stations on IFC immediately upstream (Station 28) and downstream (Station 29) of the tributary outlet showed a measureable impact by the FLT tributary on water quality in the creek. Most parameters (TN, ON, NO_3-N, NH_3-N, TP, TDP, Cl, *E. coli*, and EC) were increased from upstream to downstream in IFC. The increases in concentration ranged from a 5% increase for EC to a 5.4-fold increase for NO_3-N. In contrast, PP and TSS concentrations were decreased in IFC by the FLT tributary. This was likely due to a dilution effect by the FLT tributary as it had lower concentrations of PP and TSS than the creek.

3.15 Catch Basin Site

3.15.1 Introduction

The CAT site was a cattle feedlot, which had water quality concerns regarding run-on and runoff hydrology. During major precipitation and snowmelt events, excessive drainage from the feedlot often entered a roadside ditch and eventually flowed into IFC. It was assumed that the runoff water from the feedlot was of poor quality and contributed nutrients, sediments, and bacteria to IFC during such events. Prior to the implementation of BMPs, a surface hydrology study was carried out. Based on the study, various BMP options were proposed, from which selected BMPs were implemented to reduce the risk of contaminant loss from the feedlot.

Because this BMP site was implemented late (November 2011) in the current study, the effectiveness of the BMPs could not be evaluated in terms of water quality. This sub-section documents the water quality issue, the steps taken to develop and implement a BMP plan, and the associated costs.

3.15.2 Site Description

The CAT site was a 21,000-head licensed feedlot in the northern part of the watershed, approximately 4 km east of Pincher Creek (Figure 3.3). The feedlot consisted of two sets of pens (north and south), silage pit, farmyard with buildings, two fresh water dugouts, and one catch basin, which collected runoff from the pens (Figure 3.147). A settling pond at the southwest corner of the north pens was used to settle solids from pen runoff before draining through two culverts into a channel to the catch basin. The catch basin collected runoff from the north and south pens and the surrounding hillside through drainage channels in the feedlot. The liquid content of the catch basin was applied to a nearby field using a pump and pivot irrigation system. Because of its location on a hillside, the feedlot was challenged to manage the runoff from the surrounding area that became contaminated by flowing through the feedlot. Elevation relief from the north to the south feedlot pens was approximately 29 m, with an average slope of about 4.5%.

A wooden fence along the west side of the feedlot trapped snow from the dominant westerly winds in the winter. In the spring and during Chinook events, snowmelt from the trapped snow drained into the catch basin. During years of high precipitation, runoff from the feedlot and trapped snow overwhelmed the feedlot drainage system, and the catch basin capacity was exceeded. The catch basin then overflowed into an adjacent road ditch, which drained into IFC, approximately 640 m west of the feedlot.

Previously, the feedlot operator considered increasing the size of the catch basin by excavating the southeast corner of the basin. However, results from a hydrological *in-situ* test, which was carried out along the east side of the catch basin, proved that this was not a viable option. This test took about 2 hr to complete, and it involved the installation of a test well, filling the well with water, and recording the depletion rate of the water from the well. The next step was to carry out a surface-hydrology study and develop a drainage plan for the site.

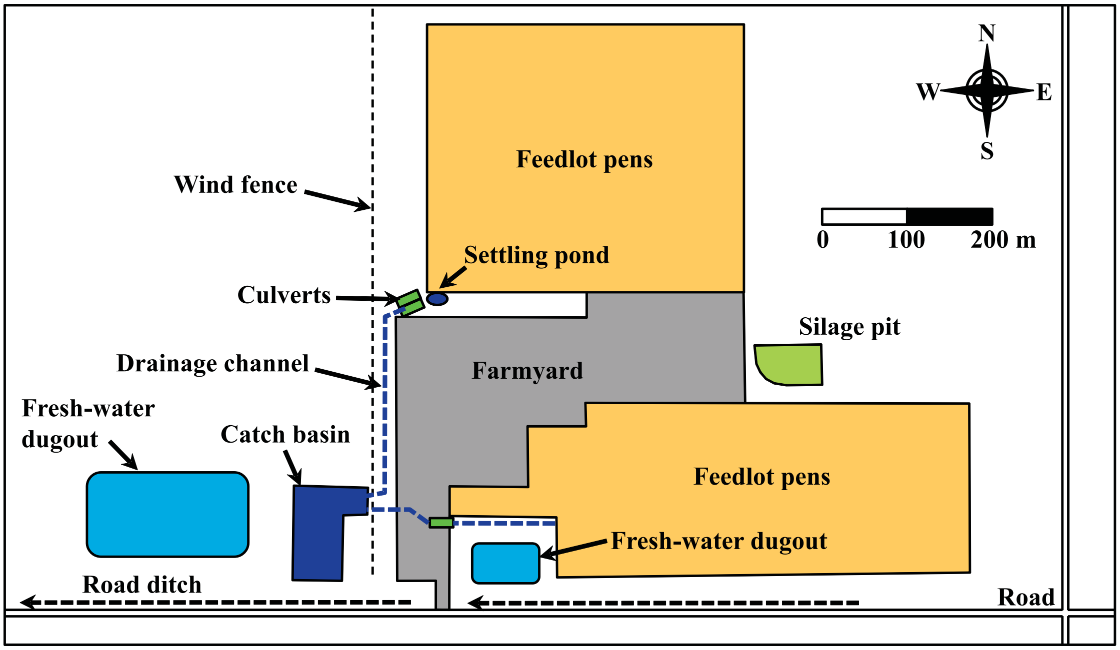

Figure 3.147. A schematic of the Catch Basin site showing the layout of the feedlot including fresh-water dugouts, catch basin, and drainage channels.

3.15.3 Surface Hydrology Study

A contractor was retained to carry out a surface hydrology study of the CAT site and to develop a water management plan. The study was carried out in 2012. The Storm Water Management Model (SWMM) was used for runoff modelling and was based on a 30 yr/24 h rain-storm event, as this is the specified single event storage capacity for a feedlot catch basin as outlined in the Alberta Agricultural Operation Practices Act and Regulations (Province of Alberta 2010). Based on schedules in the Act, the contractor used 100 mm for a 30 yr/24 h storm event for the Pincher Creek area and a 70% runoff coefficient for feedlot surfaces. Topographical data of the site were obtained using a global positioning system. For modelling, a modified Chicago design storm was used based on Environment Canada weather data. Further details about the modelling procedure are presented in Hasegawa Engineering (2012).

Using the topographical data, the feedlot and surrounding area were divided into nine catchments based on grade, direction of slope, and land use (Figure 3.148). It was determined that Catchments 1 to 4 and 6 to 9 contributed runoff that drained to the catch basin at the southwest corner of the feedlot facility (Hasegawa Engineering 2012). Catchment 5 bypassed the feedlot on the east side and runoff from this area entered a roadside ditch. It was noted that Catchments 1 to 3 were offsite drainage areas that drained directly to the settling pond and catch basin; whereas, Catchments 4 and 8 were offsite drainage areas that generated run-on to the feedlot area. Hasegawa Engineering (2012) suggested that (1) drainage from Catchments 1 to 3 should be directed around the settling pond and catch basin (Area A), (2) a new storage area be constructed in Catchment 9 (Area B), and (3) drainage from Catchment 4 be re-directed to the east side through a constructed ditch (Area C) (Figure 3.149).

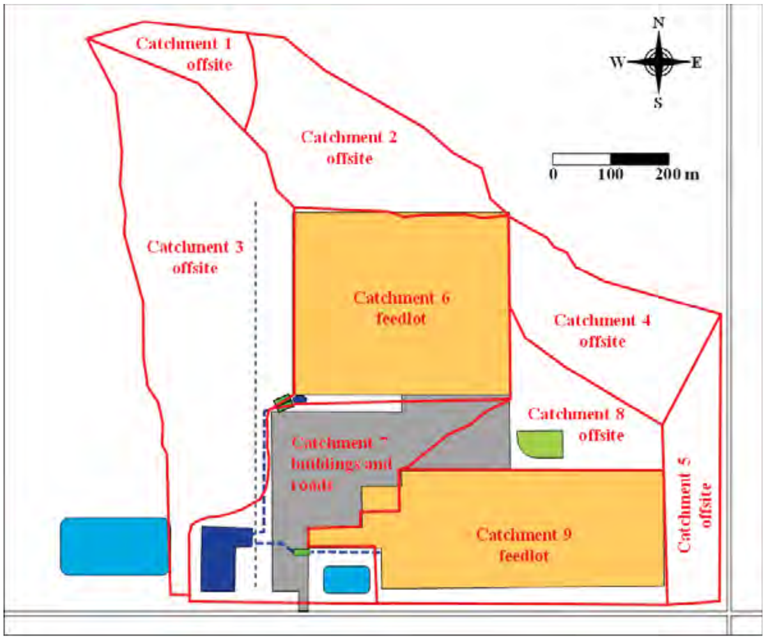

Figure 3.148. Catchments identified through the surface hydrological survey carried out at the Catch Basin site in 2012. Adopted from Hasegawa Engineering (2012).

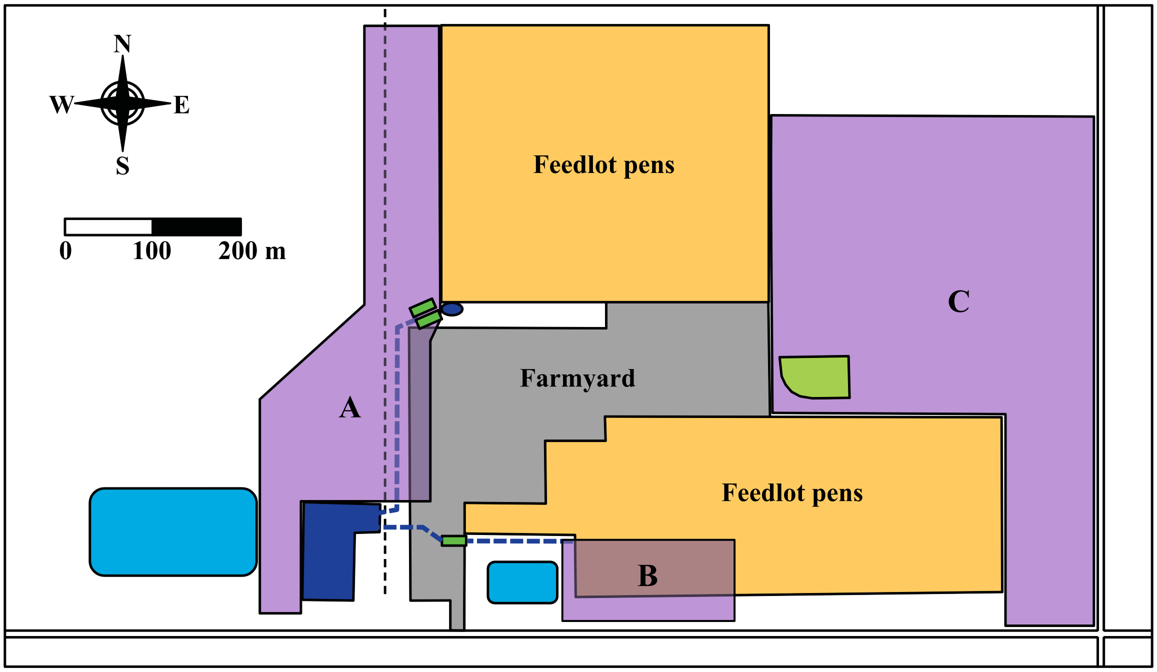

Figure 3.149. Areas (A, B, and C) identified for improved runoff and run-on control at the Catch Basin site.

Area A included Catchments 1 to 3, which consisted solely of drainage from the hill slope and snow trapped by the west fence. This runoff, along with runoff from the north feedlot pens, entered the settling pond. The settling pond drained through two road culverts into a single drainage channel to the catch basin. The suggested plan for Area A was to construct a new north-south channel along the west side of the feedlot to direct the hill slope and snowmelt runoff past the settling pond and catch basin, into the roadside ditch along the south side of the property.

Area B represented a secondary or emergency containment for excess levels of feedlot runoff. A storage capacity of 9600 m^3 was recommended. However, if runoff from Catchment 4 was diverted east, and not through the south feedlot pens, the storage capacity would only need to be 6400 m^3. The new storage facility would use the east berm of the fresh-water dugout, and north and south berms would need to be constructed. A control gate and spillway would be installed in the northeast corner. The new storage facility would temporarily hold feedlot runoff until there was capacity available in the main catch basin. It was suggested that a new single 0.5-m channel to the catch basin be constructed with up-graded culverts under the access road.

Area C represented the construction of an eastside channel to divert water that typically drained through the south pens. The channel would divert water from Catchments 4 and 5 into a nearby roadside ditch along the south side of the property.

For the surface hydrology modelling exercise, it was assumed that drainage from Catchment 5 entered the roadside ditch, drainage from Catchments 1 to 4 were diverted around the feedlot, and additional storage was provided in Catchment 9 (Hasegawa Engineering 2012). All ditches were modelled as 0.5 m deep, 0.5 m across the bottom, and with 2:1 slide slopes.

Results from the model showed that the existing catch basin storage is adequate if additional storage is created in Catchment 9 (i.e., Area B), along with Catchments 1, 2, 3, and 4 channelled around the feedlot (Tables 3.107 and 3.108). If drainage from Catchment 4 is diverted to the east ditch, precautions need to be taken to control erosion from the resulting concentrated flow and high velocities (Hasegawa Engineering 2012).

Table 3.107. Modelling results for Catchments 1 to 9 at the Catch Basin site (Hasegawa Engineering 2012).

				Runoff			
Catchment	Area (ha)	Percent impervious	Run-on (mm)	Volume (m^3)	Peak flow ($m^3\ s^{-1}$)	Final outlet	Runoff coefficient
1	2.46	0	0	1,180	0.32	West ditch	0.479
2	7.94	0	14.8	4,750	0.79	West ditch	0.521
3	18.98	0	25.1	12,360[z]	1.12	West ditch	0.521
4	6.5	0	0	3,220	1.34	Catch basin or east ditch	0.469
5	4.03	0	0	1,890[z]	0.43	East ditch	0.469
6	12.47	100	0	8,550[z]	0.75	Catch basin	0.686
7	10.33	22.3	0	5,480[z]	1.95	Catch basin	0.531
8	5.85	0	57.7	5,910	1.65	Area C/catch basin	0.671
9	12.19	100	48.5	14,330[z]	1.93	Area C/catch basin	0.792
Total	**80.48**			**42,610**			

[z] Volume used in determining total runoff volume. Runoff is tracked multiple times if it moves from one catchment to another. Therefore, individual catchment runoff volumes cannot be summed to achieve a total runoff volume.

Table 3.108. Modelling results for storage nodes at the Catch Basin site (Hasegawa Engineering 2012).

Nodes	Max. volume[z] (m^3)	Peak flow ($m^3 s^{-1}$)	Max. % full (m)	Max. depth (m)	Max. velocity ($m s^{-1}$)
Settling pond	147	0.752	50	0.65	n/a
Catch basin	20,564	1.952	99	3.94	n/a
Area B	9,092	1.928	98	1.18	n/a
West ditch	12,356	1.204	n/a	Not modelled	Not modelled
East ditch	1,889	0.427	n/a	Not modelled	Not modelled

[z] Storage nodes still have freeboard when full.

Hasegawa Engineering (2012) identified four design concerns based on the results obtained from the modelling exercise:

1. The maximum velocities in some channels exceeded 3 m s^{-1} due to the slope of the hill, and this may be an erosion risk.

2. For Area B (Catchment 9), channel capacity was increased for the model exercise. However, the channel and two culverts (0.3 m diameter) were still inadequate. Flooding would occur unless the slope was increased by burying the culverts deeper and using larger culverts.

3. The existing culvert (0.2 m diameter) for the fresh-water drainage channel (Sub-section 3.15.4) that exited to the road ditch was undersized. An upgrade would require increasing the culvert capacity and raising the surface of a private access road to accommodate larger culverts. The alternative was to leave the culvert as is and allow water to overtop the road and enter the road ditch. However, this may cause erosion damage to the access road.

4. The settling pond was modelled without achieving settling velocities. When more depth was added, stagnant water was predicted. A possible solution would be to lower the settling pond, culverts, and channels connecting this infrastructure.

3.15.4 Implementation and Cost of Beneficial Management Practices

The BMP plans for Areas A, B, and C were considered and the feedlot operator decided to only implement the Area A plan. The plans for the other two areas may be implemented at a later date. Area A plan addressed the runoff water from Catchments 1 to 3. This was achieved by constructing a shallow (<0.5 m deep) fresh-water drainage channel, starting just north of the two settling pond culverts. This channel intercepted runoff from the area between the wind fence and feedlot (Figure 3.150) before it entered the settling pond. The new channel was parallel to the channel from the settling pond to the catch basin. The new fresh-water channel then followed around the north and west sides of the catch basin and exited into the roadside ditch. The fresh-water channel prevented uncontaminated (i.e., snowmelt) runoff from entering the settling pond and mixing with feedlot pen runoff.

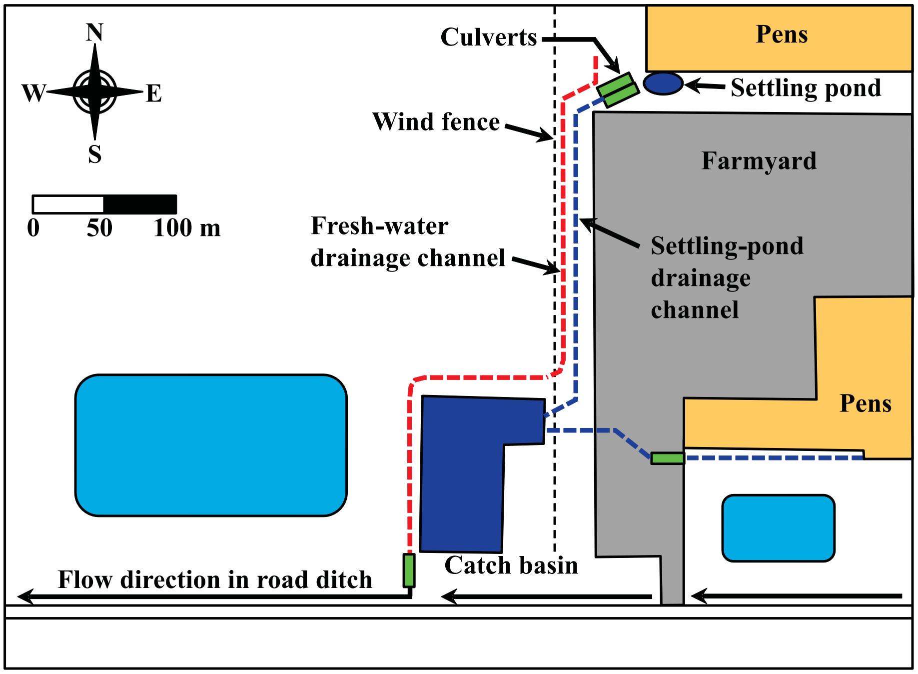

Figure 3.150. Location of the new fresh-water drainage channel at the Catch Basin site.

In addition to construction of the fresh-water channel, the settling pond and the drainage channel from the settling pond to the catch basin were excavated to increase their capacities. The soil removed in construction of the fresh-water channel and from cleaning of the settling pond and channel was used to create a slightly raised berm between the two channels. As well, the two settling-pond culverts were cleaned of obstructing material.

As indicated previously, the option for expanding the catch basin was not feasible. However, solids and sediment were removed from the catch basin to restore its original holding capacity. Construction of the drainage improvement for Area A was started in November 2012 and completed in December 2012. The total cost of implementing the BMPs for Area A was $13,200 (Table 3.109). Most of the cost (83%) was the excavation work on the channels and cleaning the catch basin. It was estimated that work in Areas B and C would have cost an equivalent amount if completed.

In spring 2013, surface runoff from Catchments 1 to 3 was diverted around the catch basin and into the roadside ditch (Figure 3.151). This meant that less water entered the catch basin and the runoff was not contaminated by mixing with feedlot runoff in the settling pond and catch basin. The CAT site was a good example of a grandfathered feedlot (i.e., an operation established prior to the Agricultural Operation Practices Act) taking steps to address its environmental concerns. This site also demonstrated that even though several BMPs were suggested, a producer may decide, for a variety of reasons (e.g., time restrictions, disruption of operation, cost), not to implement all BMPs. The implementation of the BMP plan for Area A was a good initial step to reduce runoff amounts from the feedlot by diverting clean runoff around the feedlot. Although reduced, the potential risk of exceeding the capacity of the catch basin still remained for major precipitation events without the implementation of the extra storage capacity proposed for Area B. Emptying the catch basin in a timely manner was an important management practice and the BMP options for Area B and C remain viable for future improvements at this site.

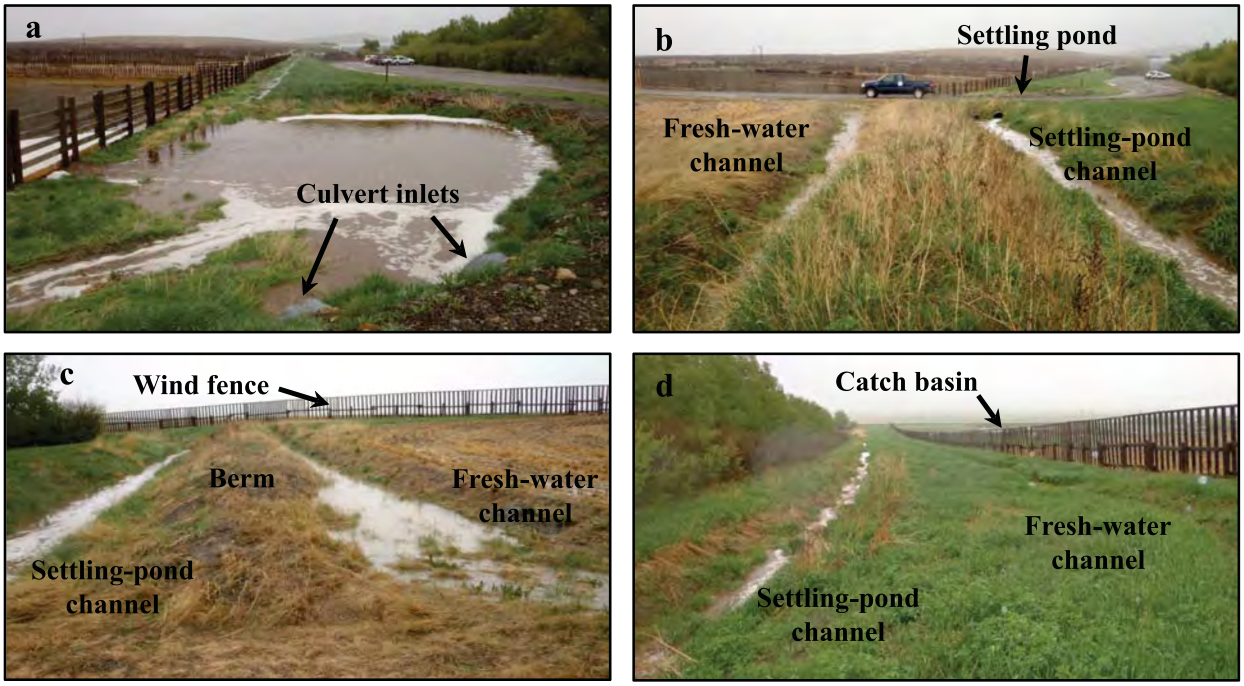

Figure 3.151. Images taken on May 23, 2013 showing (a) the settling pond at the southwest corner of the north pens, (b) the settling-pond channel and fresh-water channel looking upstream towards the settling pond, and (c) downstream immediately exiting the culverts and (d) closer to the catch basin, flowing parallel to the wind fence.

Table 3.109. Cost of beneficial management practices implementation for Area A at the Catch Basin site in 2012.

Item	Cost ($)	Labour (h)
Excavation and berms	5,000	10
Cleaning sediment from catch basin	5,000	10
Cleaning sediment from settling pond and culverts	1,000	8
Catch basin hydrological *in-situ* test	2,200	4
Total	**13,200**	**32**

3.15.5 Conclusions

- The CAT site had runoff issues during high precipitation events because of local topography, run-on from offsite areas, and undersized storage capacity. The catch basin was subject to overflowing and draining into ditches leading to IFC.

- After a detailed site assessment, mitigation options (i.e., BMPs) were available for three areas within the CAT site to help control potential run-on to the feedlot and runoff from the feedlot.

- Although BMPs were suggested for three areas within the feedlot, not all BMPs were implemented by the producer for various reasons.

- The implementation of the BMPs in Area A successfully prevented fresh-water run-on from entering the feedlot area and catch basin. It was diverted around the catch basin and into a roadside ditch.

- Without the development of additional storage capacity proposed for Area B, the catch basin was still at risk of overflowing during high precipitation events. Emptying the catch basin in a timely manner will continue to be an important management practice.

- The implementation of Area A BMPs was a positive improvement and the development of additional storage capacity remains as a viable option for future improvements.