6 LOWER LITTLE BOW FIELD

6.1 Introduction and Hypotheses

The Lower Little Bow Field (LLB) site was an irrigated field with a high soil phosphorus (P) concentration. Similar to the Battersea Drain Field (BDF) site (Section 5), the LLB site had high amounts of cattle manure application, lending to its high soil P concentration. The LLB site was previously used in the Alberta Soil Phosphorus Limits Project to monitor water and soil phosphorus from 2002 to 2005 (Little et al. 2006). They reported that annual mean soil-test phosphorus (STP) ranged from 236 to 269 mg kg^{-1} and total phosphorus (TP) in runoff water ranged from 1.15 to 3.94 mg L^{-1} at this site.

The elevated STP and the high concentrations of nutrients in the runoff were the main concerns with this site. The loss of fecal bacteria (*Escherichia coli*) in runoff was also examined. Similar to the BDF site, the beneficial management practices (BMPs) were developed to address (1) the source of nutrients and (2) the transport of nutrients from land to surface water. The BMPs implemented to address nutrient source included (1) the cessation of manure application to address soil P concentration and (2) using a nutrient management plan for soil nitrogen (N). The BMPs implemented to address nutrient transport included (1) modification to the pivot irrigation system to limit water application in the drainage channel, (2) utilization of the Alberta Irrigation Management Model (AIMM) to schedule irrigation events, and (3) establishment of grass cover in the drainage channel. Soil and runoff water quality were monitored for 2 yr (2007 and 2008) prior to the implementation of the BMPs. The BMPs were implemented in the fall 2008 and spring 2009, and monitoring continued until 2011. Therefore, this site had 2 yr of pre-BMP monitoring (2007 and 2008) and 3 yr of post-BMP monitoring (2009 to 2011). Runoff water quality and flow were monitored using a single edge-of-field station.

The underlying assumption was that the over-application of manure was contributing excessive nutrients to the soil, making these nutrients, as well as fecal bacteria, more susceptible to loss in rainfall, snowmelt, and irrigation runoff. The hypotheses were:

- The cessation of manure application BMP would reduce STP, soil nitrate nitrogen (NO_3-N), and soil ammonium nitrogen (NH_4-N) concentrations, and subsequently reduce dissolved P and N concentrations in runoff. Reductions in chloride (Cl) and *Escherichia coli* (*E. coli*) concentrations were also expected.
- The grass channel BMP would reduce the concentration of total suspended solids (TSS) and particulate phosphorus (PP) in runoff.
- The irrigation management BMP would reduce the amount of irrigation runoff and nutrient loss.

6.2 Methods

6.2.1 Site Description and Management

The LLB site included two adjacent quarter sections (west and east) of land approximately 45 km northeast of Lethbridge (Figure 5.1). The site was 130 ha in size, but the actual BMP drainage area within the two quarter sections was about 89 ha (Figure 6.1). During the study, the quarter sections were used for annual crop production (Table 6.1); however, forages were also grown in the past. The site was within the Lower Little Bow Watershed and part of the Lethbridge Northern Irrigation District. The site was irrigated with two centre pivot irrigation systems. Beef cattle manure from the producer's nearby feedlot had been applied regularly to the site.

Table 6.1. Annual crop rotation and yield at the Lower Little Bow Field.

Year	Quarter section	Crop[z]	Seeding date	Harvest date	Yield (Mg ha^{-1})[y]
2006	West, East	Corn silage	na[x]	na	na
2007	West, East	Corn silage	na	na	na
2008	West [w]	Canola silage	May	June	13.45
	West [w]	Barley silage	June	na	17.94
	East	Canola	May	October	3.92
2009	West, East	Corn silage	May 4	September 16	47
2010	West - north half	Corn silage	May 20	October 14	29.6
	West - south half[v]	Canola	May 20	October 13-14	2.9
	West - south half[v]	Barley silage	July 13	September 20	9
	East	Canola	May 20	October 13-14	2.9
2011	West, East	Corn silage	May 15	October 20	41.8

[z] Corn (*Zea mays* L.), canola (*Brassica napus* L.), barley (*Hordeum vulgare* L.).

[y] Silage yields are expressed on a wet-weight basis.

[x] na = not available.

[w] Due to hail damage the canola was harvested as silage and the quarter section re-seeded to barley.

[v] Due to poor germination about one-third of the area seeded to canola was tilled in early July and re-seeded to barley.

The site had a single main drainage channel, which flowed towards the northeast corner of the east quarter section (Figure 6.1). Water from the field channel drained into a culvert under the road and then into a 1.5 km long coulee, which met with the Lower Little Bow River. The drainage channel had been mechanically altered in the past. The drainage channel originally was deeper and more defined but had since been filled in to make the field more level and easier to farm. The channel alteration was obvious when compared to the coulee drainage channel on the north side of the road at water monitoring Station 101 (Figure 6.1).

Most of LLB site was within the LET1/U1l 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 Dark Brown Chernozems and included dominant (>60%) Lethbridge soil series and significant (10 to 30%) Readymade and Whitney 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 medium-textured, water-laid sediment and medium-textured till. The drainage channel in the east quarter section was within the ZUN1/SC1h AGRASID soil landscape model (Alberta Soil Information Centre 2013). Soil within this model is Miscellaneous Undifferentiated Mineral (Orthic Regisol) soil series, with well drained characteristics. Parent material is undifferentiated material. The surface soil had a sandy-loam texture (52.9% sand, 16.6 % clay), pH of 7.5, electrical conductivity of 2.8 dS m^{-1}, 2300 mg kg^{-1} TN, 1009 mg kg^{-1} TP, and 3.6% organic matter (Appendix 4).

Manure was applied and incorporated on high points of land in the east quarter section in the fall 2005 after harvest and to the entire west quarter section in spring 2006. Both quarter sections received manure in the fall of 2007. No other manure was applied for the duration of the study as part of the BMP plan.

Each of the two quarter sections was equipped with a low-pressure, drop-tube centre pivot irrigation system. Both quarter sections were generally irrigated simultaneously, except in 2008 and 2010, when different crops were grown on the quarter sections.

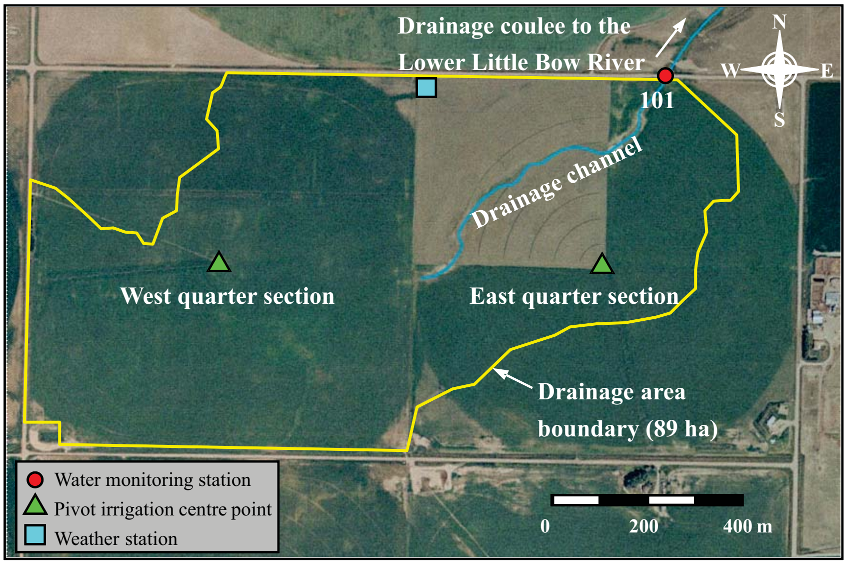

Figure 6.1. Lower Little Bow Field showing the drainage area and channel.

6.2.2 Implementation of Beneficial Management Practices

6.2.2.1 Nutrient Source Management

The nutrient source management BMPs consisted of (1) the cessation of manure application to mainly address the high STP concentration, and (2) the use of annual crop nutrient management plans to assess soil N for optimum crop growth. The cessation of manure began in the fall 2008 and manure was not applied for the remainder of the project. A crop nutrient management plan was developed each fall for the following crop year starting in fall 2008. In the fall, soil samples were collected and the soil-test results were used in the Alberta Farm Fertilizer Information and Recommendation Manager (AFFIRM) program (AFRD 2005b) to determine crop nutrient recommendations. Details about soil sampling are provided in Sub-section 6.2.4.

6.2.2.2 Nutrient Transport Management

Grass channel. In spring 2009, grass was established on about 2 ha of land in the drainage channel in the east quarter section immediately upstream from the edge-of-field water quality monitoring station (Figure 6.2). The grass channel was intended to reduce sediment transport and increase runoff infiltration. The area was tilled by the producer in the week prior to seeding. A tractor and a seed drill were rented from another producer. The seed mix, recommended by Viterra Seeds in Lethbridge, was Salinemaster (Table 6.2). The seeding rate was 11.2 kg ha^{-1}; however, the

Figure 6.2. The grass channel and zone of no irrigation application beneficial management practices implemented in the east quarter section at the Lower Little Bow Field.

actual rate of application may have been slightly higher as the seed drill was difficult to set for this rate. No fertilizer was applied with the seed as per dealer recommendation. The channel was seeded on April 22, 2009 (Figure 6.3). At least one pass with the approximately 6-m wide seed drill (Figure 6.3b) was made on either side of the drainage channel. An additional 6-m wide pass was carried out through much of the southern portion of the area. The lower area of the channel between the monitoring station and the lower end of the wet area was seeded in an east-west direction, perpendicular to the direction of flow. After seeding, flags were placed around the boundary of the seeded area.

The grass germinated and established well. Unfortunately, near the end of June 2009 the grass was accidently sprayed with a herbicide, effectively killing the grass (Figure 6.4a). The area was re-seeded on July 3, 2009 using the same seed mix, seeding rate, and seeding equipment. The re-seeding was successful and a healthy grass cover was established (Figure 6.4b).

Table 6.2. Composition and planting rate of Salinemaster mix at the Lower Little Bow Field.

Variety	Percent of blend by weight	Seeds kg^{-1}	Planting rate (seeds m^{-2})	Planting rate (kg ha^{-1})
AC Saltlander green wheatgrass^{z}	40	259,912	116	4.48
Proven hps brand smooth brome^{y}	20	299,559	67	2.24
Proven hps brand tall fescue^{x}	30	499,449	168	3.36
Slender wheatgrass^{w}	10	319,604	36	1.12

[z] *Elymus hoffmannii* Jensen and Asay
[y] *Bromus inermis* L.
[x] *Festuca arundinacea* Schreb.
[w] *Elymus trachycaulus* (Link) Gould ex Shinners

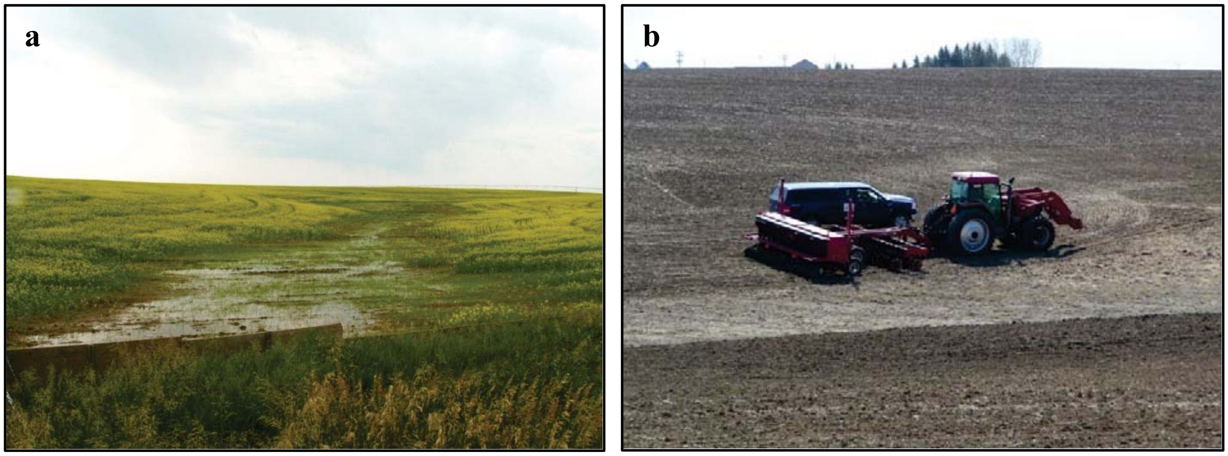

Figure 6.3. Drainage channel (a) prior to the seeding of grass (July 8, 2008) and (b) during seeding of grass (April 22, 2009).

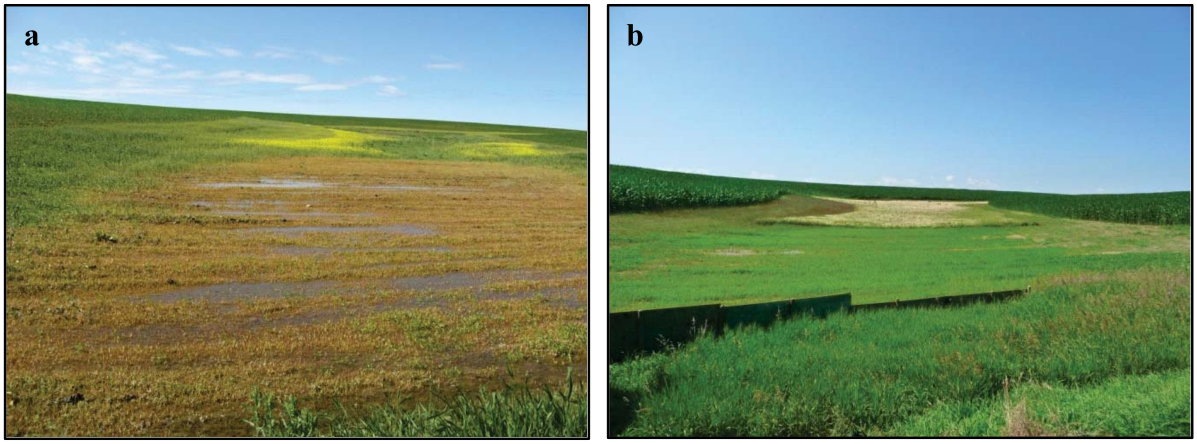

Figure 6.4. The grass channel as it appeared just south of monitoring station (a) after being sprayed with a herbicide in late June 2009 and (b) on July 29, 2009 after re-seeding.

Irrigation management. Irrigation management was a large component of nutrient transport management. The irrigation management BMP consisted of two parts: (1) the pivot irrigation system modification and (2) the utilization of AIMM to schedule irrigation.

In order to reduce the volume of irrigation runoff, the pivot irrigation system in the east quarter section was modified so that some of the sprinklers were turned off when the pivot moved through the drainage channel. The pivot system had seven spans (each span was 53 m long) with a set of wheels at the end of each span. A suspension arm extended from the last span. In spring 2009, solenoid valves were installed on the last two spans and the suspension arm. A new control panel (RPM preferred model, Reinke Manufacturing Company, Inc., Deshler, Nebraska) was installed at the pivot point and a global positioning system (GPS) was mounted on the pivot. The control panel and GPS unit were used to control the solenoid valves. The pivot moved in a clockwise rotation and the valves were closed as the pivot approached the drainage channel from the west and then opened on the east side of the channel (Figure 6.2). The new control panel was programmed and calibrated by the landowner, but was not used during the initial irrigation periods in early July 2009 as the area in the grass channel was dry and needed water. After July, the panel was programmed so that the designated sprinklers were turned off over the drainage channel (Figure 6.2). Additional adjustments were made on when or where nozzles were turned off and on in spring 2010.

The flow of irrigation water through the pivot system on the east quarter section was measured using a McCrometer propeller flow meter (model RE100; McCrometer, Hemet, California) and recorded by a Lakewood datalogger (model CP-X; Lakewood Systems Ltd., Edmonton, Alberta) every 15 min. The McCrometer was installed on the water delivery pipe just before where the pipe attached to the centre pivot.

The AIMM program is a decision support tool used to assist producers with planning irrigation to maximize crop production (ARD 2013a). This model was chosen to assist in irrigation recommendations for maximum crop productivity and avoiding runoff from over-irrigation. The required input information for the model included crop type, seeding date, weather data, soil texture, initial soil moisture content, root-zone depth, allowed depletion of total available water

(TAW), and daily irrigation amounts. The model used the American Society of Civil Engineers ASCE standardized evapotranspiration equation (modified Penman-Monteith equation) for calculating reference evapotranspiration. The model is described in more detailed in Sub-section 5.2.2.2. Initial soil moisture content used to initiate the model was determined by collecting soil samples from a representative location within the irrigated area. Soil samples were collected after the crop was seeded (Table 6.3). Additional soil moisture samples were collected in 2010 and 2011 during the irrigation season to verify and adjust the model output.

Although the model was run for both quarter sections, results of one quarter section are presented in the report since irrigation was generally applied to both quarter sections simultaneously, except in 2010 when different crops were grown on each quarter section. Five rain gauges on the two quarter sections were monitored twice weekly for the irrigation water and rain inputs for the model. The model was run once per week and the AIMM output and irrigation recommendations were delivered and discussed with the producer on a weekly basis.

6.2.3 Weather

An automated weather station (LWS1) was installed at the site in May 2008 (Figure 6.1). The station recorded air temperature, precipitation, and relative humidity from May 2008 to the end of 2011 (Sub-section 2.4.2). Therefore one partial year (2008) and three complete years (2009 to 2011) of weather data were collected. The nearest Irrigation Management Climate Information Network (IMCIN) weather station near LWS1 was 16.5 km southwest from the site near Iron Springs. Data from Iron Springs (IMCIN) were used for the AIMM and downloaded through AgroClimatic Information Services (ARD 2013b). The Lethbridge Canada Department of Agriculture (CDA) weather station provided the nearest 30-yr normal values from historical data (1971 to 2000) (Environment Canada 2013), which were not available from the Iron Springs station.

Table 6.3. Soil moisture sampling dates and measured total available water for 2009 to 2011 at the Lower Little Bow Field.

Year	Quarter section	Initiation sampling date	Initial measured total available water (mm)	Adjustment sampling date[z]	Adjusted measured total available water (mm)
2009	East	June 28	132	-	-
2010	East	May 13	159	July 13	129
				August 6	164
	West	May 13	159	July 13	171
				July 29	171
				August 10	171
2011	East	June 1	142	July 18	127

[z] Soil moisture samples were collected on an approximate three-by-three grid (i.e., nine sampling points; 267 m between samples) in each quarter section. At each sampling point, samples were collected from fours layers (0 to 25 cm, 15 to 50 cm, 50 to 75 cm, and 75 to 100 cm). Moisture content was determined by drying samples at 105 °C for 24 h.

6.2.4 Soil Sampling

Soil characterization samples (Sub-section 2.9) were collected on April 20, 2010 in the west quarter section and on October 27, 2010 in the east quarter section. Soil samples collected annually at this site included 0- to 15-cm agronomic samples (2007 to 2011) and 0- to 60-cm soil-test samples (2008 to 2011) (Figure 6.5; Sub-section 2.9). The agronomic samples were collected in the spring and fall each year and the results were used to interpret runoff water quality data. To determine STP changes with time, the results were compared to the values obtained for this site during the Alberta Soil Phosphorus Limits Project (Little et al. 2006). The soil-test samples were collected to determine soil nutrient recommendations using the AFFIRM program and this was part of the BMP nutrient management plan. Soil-test samples were collected in the fall and the results were used to make soil nutrient recommendations for the following crop year.

Surface samples from 0 to 2.5 cm were also collected in fall 2011 in conjunction with the agronomic samples using the 200-m grid (i.e., 23 sampling points). Samples were collected using the frame-evacuation method (Nolan et al. 2006 and 2007), which consisted of driving an 11- by 60-cm steel frame into the ground until the top of the frame was at ground level. The soil sample was then collected from within the frame with a 2.5-cm deep shovel.

Statistical analyses of the agronomic soil samples comparing annual means were completed using SAS version 9.2 (SAS Institute Inc. 2008). The Univariate procedure was used to test the distribution of the data and the Means procedure was used to generate descriptive statistics. Differences between pre- and post-BMP periods were tested using the Least Squared Means test in the Mixed procedure with unstructured variance components with the repeated and pdiff options. A significance level of $P < 0.1$ was used.

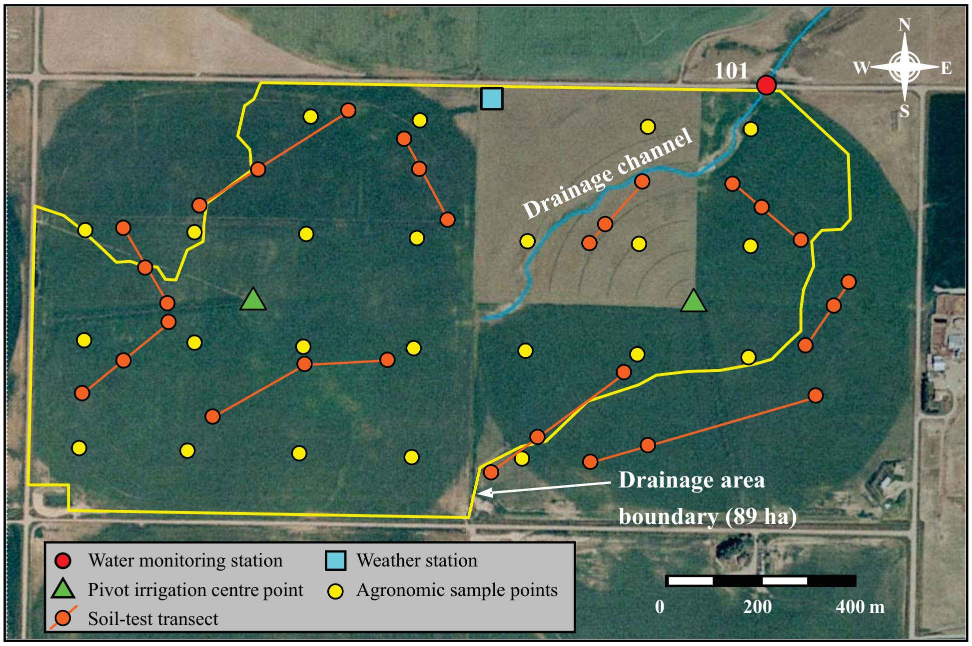

Figure 6.5. Sampling points for the agronomic and soil-test samples at the Lower Little Bow Field.

6.2.5 Manure Sampling

Solid beef manure samples were collected in September 2007. Immediately after manure was applied to the study site in fall 2007, six samples were collected from the soil surface. Samples were analyzed for moisture and chemical content (Sub-section 2.10).

6.2.6 Water Flow and Quality

The LLB site was equipped with a single edge-of-field monitoring station, which consisted of a circular flume and automated water sampler (Sub-sections 2.6 and 2.7) (Figures 6.1 and 6.6). A total of 34 snowmelt, 53 rainfall, and 29 irrigation runoff samples were collected from 2007 to 2011. When runoff events included irrigation and rainfall, those with <25 mm rainfall were treated as irrigation events and those with >25 rainfall were treated as rainfall events. Samples were analyzed for N and P parameters, total suspended solids (TSS), Cl, pH, electrical conductivity (EC), and *E. coli* (Sub-section 2.8.3). Annual loads in runoff were calculated as described in Sub-section 2.8.4.

For statistical analysis between the pre- and post-BMP periods, snowmelt runoff data were not included as there was no snowmelt during the pre-BMP period. Comparisons between the two periods were made for rainfall, irrigation, and the combination of these two event types (growing season). The 2009 data were excluded from the statistical analysis because the grass channel was tilled and re-seeded in early July 2009 and this caused an increase in sediment loss in runoff. Further details about the statistical analysis are in Sub-section 2.8.4.

Figure 6.6. Rainfall runoff entering the flume at the edge-of-field monitoring station at the Lower Little Bow Field on May 28, 2010.

6.3 Results and Discussion

6.3.1 Weather

Data obtained from the Iron Springs weather station and the 30-yr average values from the Lethbridge CDA weather station are summarized in Sub-section 5.3.1. Briefly, annual average daily temperature was generally less than the 30-yr average, except for 2007 (Table 5.3). Overall, 2009 had the coolest average temperature compared to the other years. Total annual precipitation was 6 to 24% higher than the 30-yr average from 2008 to 2011 and 27% less than the 30-yr average in 2007 (Table 5.4).

The pre-BMP years (2007 and 2008) were generally warmer and drier than the post-BMP years (2009 to 2011). The average temperature was 5.7 °C for the pre-BMP years and 4.8 °C for the post-BMP years. The average annual precipitation was 332 mm for the pre-BMP years and 409 mm for the post-BMP years.

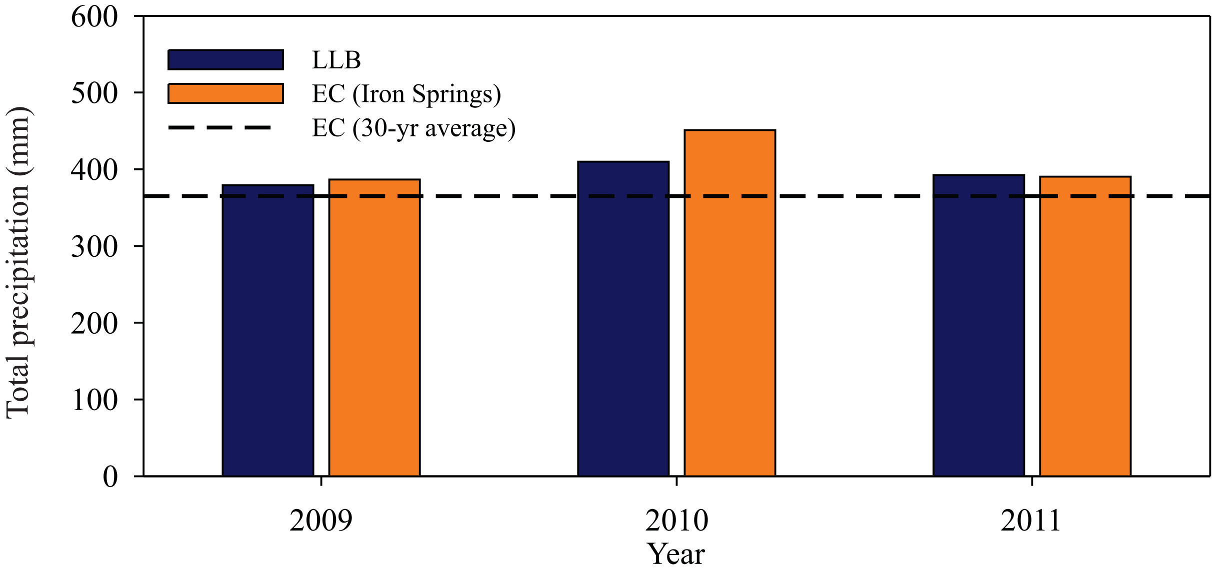

Figure 6.7. Total precipitation at the Lower Little Bow Field (LLB) weather station compared to the Environment Canada (EC) Iron Springs weather station from 2009 to 2011. Note that LLB weather station was not active in 2007 and only active for a portion of 2008.

Table 6.4. Average water and nutrient content of manure sampled in relation to Lower Little Bow Field in 2007.

Sampling date	Number of samples	Water	NH_4-N[z]	TN	TP	TK	TS
		----------	----------	---------- (kg Mg^{-1})	----------	----------	----------
Sep 2007[y,x]	6	789	6.26	12.8	6.12	19.5	3.56

[z] NH_4-N = ammonium nitrogen, TN = total nitrogen, TP = total phosphorus, TK = total potassium, TS = total sulphur.

[y] Exact sampling date is unknown.

[x] Average values are expressed on a dry-weight basis.

Annual total precipitation at the LLB weather station was similar to the Environment Canada Iron Springs station, suggesting the weather data collected at the site are accurate (Figure 6.7). The difference was greatest in 2010 when about 9% less precipitation was recorded at the LLB weather station compared to the Iron Springs weather station.

6.3.2 Manure

The water and nutrient content of manure sampled in 2007 is presented in Table 6.4. In comparison to values reported by Olson et al. (2003, 2010a,b) and Olson and Papworth (2006) for feedlot beef manure in southern Alberta; the NH_4-N concentration was higher; TN, TP, and total potassium concentrations were lower; and total sulpher concentration was similar for the manure applied at the LLB site in fall 2007.

6.3.3 Soil

6.3.3.1 Agronomic Samples

Extractable NO_3-N concentration in the 0- to 15-cm agronomic samples was generally higher in the spring compared to the fall of the same year (Table 6.5). Adequate NO_3-N concentration for irrigated crops was estimated to range from 20 to 30 mg kg^{-1} in the 0- to 15-cm soil layer, based on information from Soil Test Technical Advisory Group (1988) and McKenzie et al. (2013). By comparison, the soil NO_3-N concentration at this site was higher on average throughout the project. The highest concentration was measured in spring 2009 at 65 mg kg^{-1}. In spring 2010, an application of N fertilizer in the form of urea at a rate of 112 kg ha^{-1} could explain the fairly high concentrations observed in the spring and in the fall. Nitrate N concentration among years was significantly different but no trends were observed. In contrast, extractable NH_4-N significantly decreased with time (Table 6.5). In fall 2007, NH_4-N concentration was particularly high (13.4 mg kg^{-1}) compared to the other years in spring and fall. The cause of this high value was likely related to sample timing, which was shortly after manure incorporation, and may have been before the conversion of NH_4-N to NO_3-N was complete.

Table 6.5. Average concentrations for nitrate nitrogen (NO_3- N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for the agronomic samples (0 to 15 cm) collected from 2007 to 2011 at the Lower Little Bow Field.

	Sampling dates		NO_3-N		NH_4-N		STP	
Year	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
			(mg kg^{-1})					
2007	May 18	Oct. 16	62*a*[z]	41*a*	4.9*a*	13.4*a*	221*c*	263*b*
2008	Jun. 17	Oct. 27	13*c*	20*c*	4.2*ab*	3.7*b*	255*bc*	347*a*
2009	May 22	Oct. 5	65*a*	22*c*	3.8*bc*	3.6*bc*	248*c*	294*ab*
2010	Jul. 9	Nov. 2	54*a*	35*ab*	3.3*c*	3.2*cd*	317*a*	273*b*
2011	Jun. 27	Oct. 26	36*b*	27*bc*	2.4*d*	2.9*d*	301*ab*	282*b*

[z] Average concentrations within each column followed by the same letter are not significantly different at $P < 0.1$.

Manure application ceased in fall 2008 as part of the nutrient source BMP plan, and 2009 to 2011 was considered the post-BMP period. Manure was last applied in fall 2007. Ammonium N concentration was generally significantly less in the post-BMP period, particularly for 2010 and 2011 compared to 2007 and 2008 (Table 6.5). No clear trend was observed for NO_3-N concentration between the pre-BMP and post-BMP periods after the cessation of manure application. As indicated above, N fertilizer was applied in 2010.

The 5-yr average for STP was 280 mg kg^{-1}, which was about five times the agronomic threshold of 60 mg kg^{-1} (Howard 2006). Soil-test P concentrations in the spring were generally lower than in the fall, except for 2010 and 2011 (Table 6.5). This may be attributed to the delayed spring sampling that occurred in these two years because of excessive soil moisture, which restricted field access. Such late sampling may have also allowed more time for mineralization of organic P compared to previous years. The STP concentration was lowest in the spring 2007. Manure was applied in the fall 2007 and a slight increase in STP concentration was observed compared to spring 2007. The increase in STP concentration might not be attributable to manure application as there was little time to allow for mineralization of P after application. Plus, the increase in STP concentration from spring to fall was observed in most other years (Figure 6.8). The highest STP concentration was observed in fall 2008; significantly higher than fall 2007 (Table 6.5). An increase in spring STP concentration was also observed from 2007 to 2008 but was not significantly different. The cause of the increase from 2007 to 2008 is likely attributed to the manure application in fall 2007, though; field variability may have also been a factor. Soil-test P concentrations in 2009 decreased but were not significantly less than in 2008. Fall STP concentrations in 2010 and 2011 were significantly less than concentrations in fall 2008. Therefore, STP concentrations increased after the last manure application and then decreased in the following years to a level slightly higher than before the last manure application. Therefore, the stoppage of manure application did not result in an overall decrease in STP concentration by the end of the post-BMP period.

Manure application in the fall of 2007 was estimated to have added 205 kg ha^{-1} of TP based on the manure analysis in 2007 (Table 6.4) at an application rate of 60 Mg ha^{-1} (wet weight). Export of soil P was mainly by harvested crop removal. Based on the crop removal rates of P reported by the Canadian Fertilizer Institute (2001), it was estimated that P removal was 9.18 kg Mg^{-1} for canola, 0.91 kg Mg^{-1} for barley silage, and 0.97 kg Mg^{-1} for corn silage. Using the yields in Table 6.1, it was estimated that 26 to 45 kg ha^{-1} yr^{-1} of P was removed from the two quarter sections. From 2008 to 2011 (i.e., four crop seasons), about 135 kg ha^{-1} P may have been removed. Based on these estimates, there was a net gain of 70 kg ha^{-1} of TP (205 kg ha^{-1} less 135 mg ha^{-1}) from 2007 to 2011. The removal of P by crops within the relatively short timeframe of the post-BMP period was less than what was added to the soil from manure application in 2007. It is anticipated that several more years of P removal by crops are required to decrease STP concentration to an acceptable agronomic level (i.e., about 60 mg kg^{-1}).

Soil-test P at this site during the Alberta Soil Phosphorus Limits Project (Little et al. 2006) from 2002 to 2005 tended to be slightly less than during the current study (Figure 6.8). The average STP concentration from 2002 to 2005 was 215 mg kg^{-1} and the average STP concentration from 2007 to 2011 was 280 mg kg^{-1}. As outlined above, the relatively large increase in STP concentration from fall 2007 to fall 2008 may have been caused by manure application in fall 2007. After 2008, STP concentration decreased to values similar to 2007.

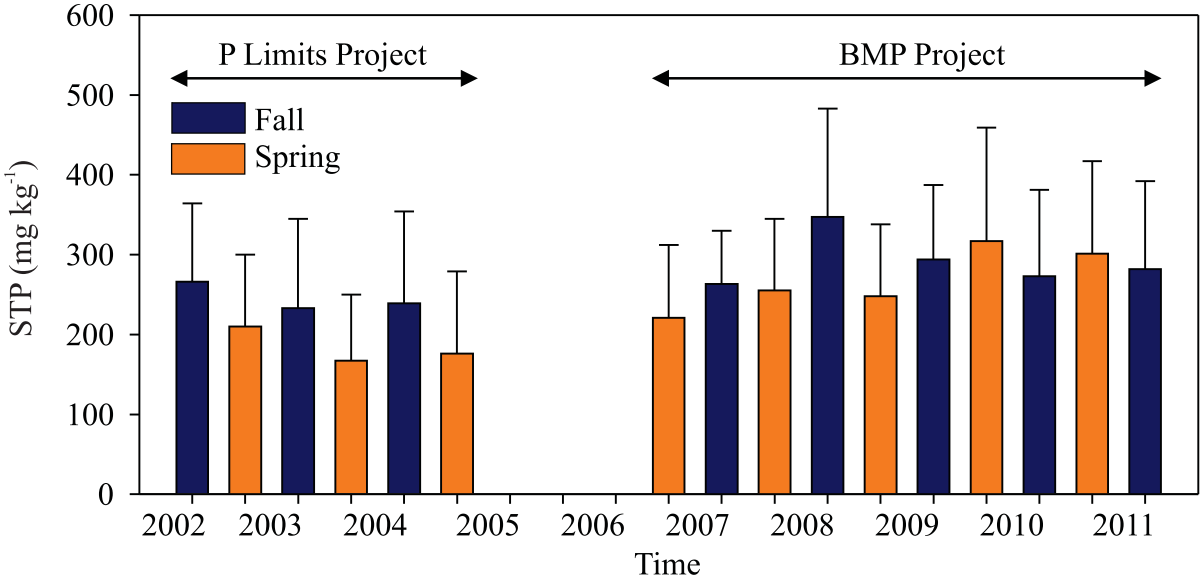

Figure 6.8. Soil-test phosphorus (STP) concentration in the 0- to 15-cm layer in the spring and fall at the Lower Little Bow Field from (a) the Alberta Soil Phosphorus Limits Project (Little et al. 2006) and (b) the Nutrient Beneficial Management Practices Evaluation Project. The T-bars are standard deviations.

6.3.3.2 Soil-test Samples

Based on the soil-test sample results (Table 6.6) and using AFFIRM, it was recommended that 39 kg ha^{-1} N fertilizer be applied for the 2010 crop year and that no N fertilizer should be applied for the 2009 and 2011 crop years. Due to the high concentration of STP, P fertilizer was not recommended to be applied during the study period, and will not be recommended to be applied in the foreseeable future.

Extractable NO_3-N concentration varied more between the two quarter sections, among the depths, and among the years as compared to extractable NH_4-N, which remained relatively stable (Table 6.6). Soil-test P concentration was consistently higher in the 0- to 15-cm soil layer and decreased with soil depth. Soil-test P is relatively immobile and accumulates near the soil surface (Chang et al. 2005; Olson et al. 2010a,b). However, as the soil surface becomes saturated with accumulated P, there is potential for P to leach to lower depths in the soil profile (Whalen and Chang 2001, Olson et al. 2010a). A relatively high STP concentration was observed in the 15- to 30-cm soil layer at the LLB site, suggesting some downward movement of P. The soil-test sample results confirmed the high nutrient concentrations found in the agronomic (0 to 15 cm) samples.

Although the soil-test samples were not collected to evaluate the effectiveness of the BMP for cessation of manure application, it is interesting to note that there was a decreasing trend in the STP concentration in the 0- to 15-cm layer from 2008 to 2011 (Table 6.6).

Table 6.6. Soil-test results for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) collected at the Lower Little Bow Field.

			NO_3-N		NH_4-N		STP	
Year[z]	Sampling date	Soil layer (cm)	East[y]	West	East	West	East	West
			----------------------------	(mg kg^{-1})	----------------------------			
2008	Oct. 27	0 to 15	29	12	3	3	282	378
		15 to 30	23	20	2	2	80	107
		30 to 60	23	28	2	2	28	27
2009	Oct. 26	0 to 15	16	10	3	3	320	261
		15 to 30	32	15	2	2	94	57
		30 to 60	44	28	2	2	9	6
2010[x]	Nov. 2	0 to 15	37	76	5	7	250	280
		15 to 30	26	33	2	2	45	70
		30 to 60	26	25	3	2	1	15
2011	Nov. 3	0 to 15	22	20	2	2	220	196
		15 to 30	21	23	1	1	70	34
		30 to 60	33	21	1	1	18	3

[z] Samples were collected in the fall and used to make soil nutrient recommendations for the following crop year.
[y] East = east quarter section, West = west quarter section.
[x] Soil samples were collected using the 200-m grid method as opposed to the transect method used in the other years.

6.3.3.3 Surface Samples

The STP concentration in the 0- to 2.5-cm layer in 2011 was within the range of values reported by Little et al. (2006) for the LLB site during the Alberta Soil Phosphorus Limits Project (Table 6.7). This suggests that cessation of manure application had little effect on STP concentration in the top 2.5-cm soil layer, which is the zone of interaction with surface runoff. However, this is based on only one sample event during the current study. The 0- to 2.5-cm STP concentration was higher compared to 0- to 15-cm layer in 2011, and this was consistent with the 2002 to 2004 results (Table 6.7).

Unfortunately, samples from this soil layer were not taken between 2004 and 2011, which may have provided further insight. It was hypothesized that after manure application was stopped, mechanical mixing through tillage and seeding may have mixed the higher STP content in this layer with lower STP concentration just below this layer, essentially resulting in a dilution effect. Perhaps the mixing zone was not deep enough to cause such a dilution effect. In a 6-yr manure application plot study in southern Alberta near Lethbridge, Olson et al. (2010b) observed STP concentration was relatively uniform above 9 cm, whereas, there was a noticeable decrease in STP concentration in the 9- to 15-cm layer. Similarly, Vadas et al. (2006) reported that in consistently well-tilled soils, P concentration is relatively uniform in its distribution in the topsoil, usually from 0 to 15 cm.

6.3.4 Runoff Flow

The annual runoff flows in the post-BMP years (2009 to 2011) were greater than in the pre-BMP years (2007 and 2008) and also greater than the flows measured from 2003 to 2005 at this site (Little et al. 2006) (Table 6.8). Flow distribution varied among years but most runoff flow occurred during the growing season (Figure 6.9). The large flow in 2010 was due to the above normal precipitation in the spring months. The even larger flow in 2011 was likely the result of saturated soil, caused by rain in September 2010 and above normal precipitation in January, May, June, and October 2011 (Sub-section 6.3.1). The hydrographs of some flow peaks in 2009, 2010, and 2011 showed a delayed recession (Figure 6.9), suggesting possible groundwater contributions in the drainage channel in the wetter years.

Table 6.7. Average Soil-test phosphorus concentration (± standard deviation) in the 0- to 2.5-cm and 0- to 15-cm soil surface layers at the Lower Little Bow Field from 2002 to 2004 and 2011.

Year[z]	0 to 2.5 cm	0 to 15 cm (fall)
	-------------------- ($mg\ kg^{-1}$)	--------------------
2002	316 ± 111	226 ± 98
2003	246 ± 121	233 ± 112
2004	254 ± 142	239 ± 115
2011	297 ± 102	282 ± 110

[z] Results for 2002 to 2004 are from the Alberta Soil Phosphorus Limits Project data (Little et al. 2006).

Table 6.8. Runoff flow measured at the Lower Little Bow Field from 2003 to 2011.

Year[z]	Flow ($m^3\ yr^{-1}$)	Percent from snowmelt	Percent from rainfall	Percent from irrigation
2003	2,968	38	5	57
2004	801	32	0	68
2005	11,238	0	92	8
2007	1,082	na[y]	na[x]	100
2008	11,637	0	40	60
2009	19,982	24	54	22
2010	26,470	20	80	0
2011	39,543	41	27	32

[z] 2003 to 2005 data from Little et al. (2006); 2007 to 2011 data from the current study. No data were collected in 2006. The pre-BMP period was in 2007 and 2008 and the post-BMP period was from 2009 to 2011.

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

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

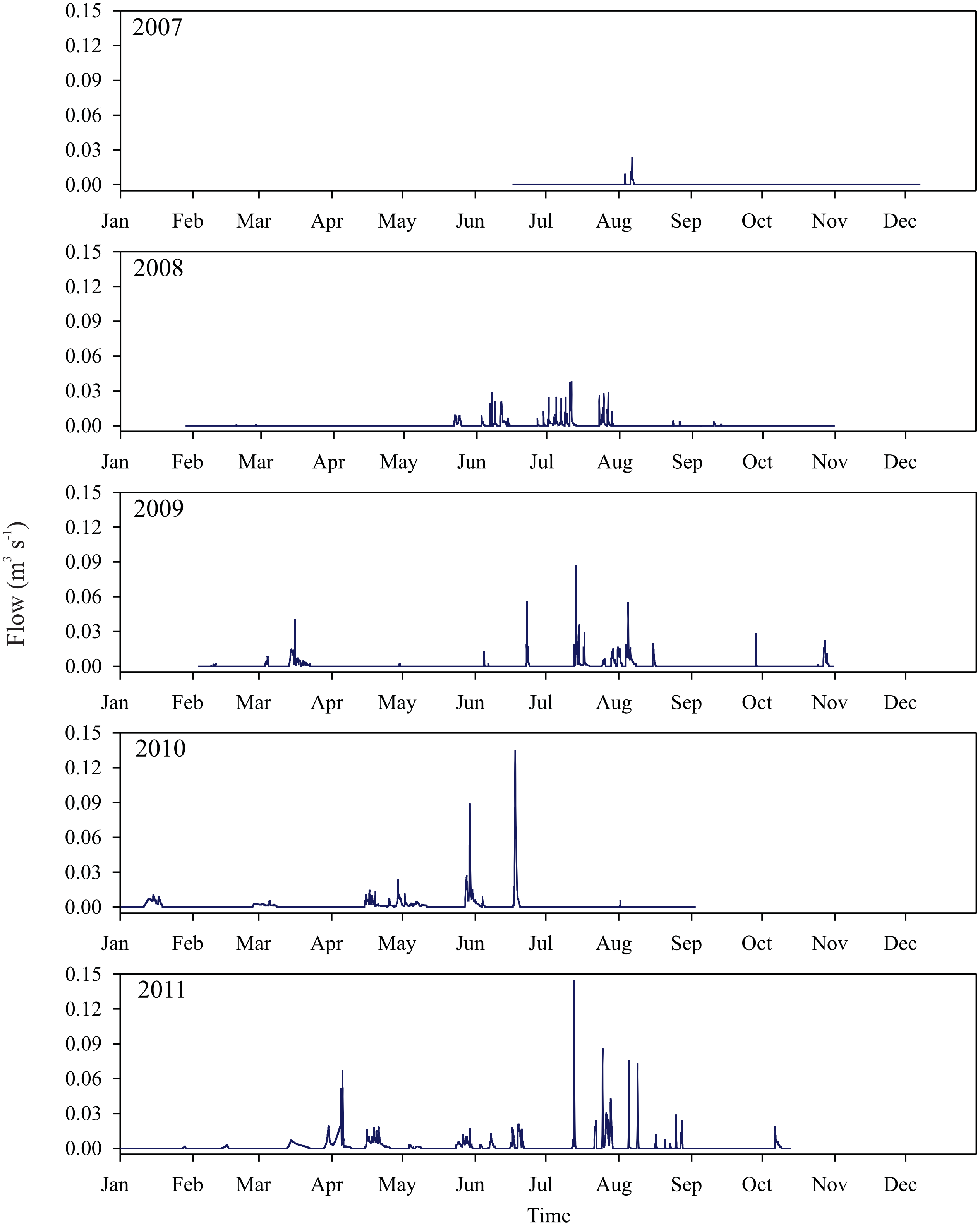

Figure 6.9. Annual hydrographs for the water monitoring station at the Lower Little Bow Field from 2007 to 2011.

In both pre-BMP years, very little snowmelt runoff occurred in 2007 and there was no snowmelt runoff in 2008 (Table 6.8). Snowmelt generated similar amounts of runoff in 2009 and 2010, with 4743 m^3 in 2009 and 5352 m^3 in 2010. The largest volume (16,047 m^3) of snowmelt was generated in 2011 compared to all other years when flow was recorded at this site.

Annual flow and proportion of runoff from snowmelt, rainfall, and irrigation varied largely from year to year (Table 6.8). The portion of annual flow from snowmelt (0 to 41%) was less variable than rainfall (0 to 92%) or irrigation (0 to 100%), The total volume of runoff water during the pre-BMP years (2003 to 2008) was from 5% snowmelt, 55% rainfall, and 40% irrigation. Rainfall and irrigation runoff were the most dominant types of runoff at this site, while snowmelt was less important.

During the post-BMP years (2009 to 2011), the average amount of runoff water was caused by 31% snowmelt, 50% rainfall, and 20% irrigation. In 2009, 20% of the flow was generated by irrigation even though the BMP was implemented. In 2010, the main runoff events occurred as snowmelt in mid-January and at the beginning of March, and as rainfall runoff from mid-April to mid-June (Figure 6.9). No irrigation runoff was generated at this site in 2010. This is in contrast to previous years when irrigation runoff contributed on average 33% of the annual flow (Table 6.8). This suggests that the pivot modification BMP (i.e., turning off nozzles as the pivot moved through the drainage channel in the east quarter section) was successful at preventing irrigation runoff in 2010 (Sub-section 6.3.6). Unfortunately, on July 21, 2011 the pivot became stuck next to the drainage channel. While stuck, the pivot continued to apply water, which drained into the channel and generated runoff. As well, after the pivot became stuck, the control settings for the solenoid values were no longer synchronized relative to the drainage channel and were not turned off over the channel for most of the season. As a result, more runoff (12,688 m^3) was generated from irrigation in 2011 compared to other years.

6.3.5 Alberta Irrigation Management Model

Results from AIMM varied annually based on management decisions made by the producer and environmental conditions.

The AIMM program was initiated on June 11, 2009, with a TAW of approximately 80% (Figure 6.10). The model was run three times during the 2009 growing season and no irrigation was recommended. In spite of what the model predicted and recommended, a total of four irrigation events took place on both quarter sections. Irrigation water was applied on June 8, prior to the initiation of the AIMM program, twice in July (12 to 17 and 23 to 26), and on September 28 after harvest. Soil moisture remained between 80 and 97% TAW until the second irrigation event (July 12), when water from two pivot system rotations (i.e., two complete rotations around the field) was applied (Figure 6.10). Towards the end of the first pivot rotation, the site received 47 mm of rainfall. The resulting TAW values were approximately 110%. Two pivot rotations of irrigation water were applied starting on July 23 and TAW content was still greater than soil field capacity (FC) at this time. In the 10 d following the end of this irrigation event, 46 mm of precipitation fell. The combination of rainfall and irrigation in July maintained the soil moisture near or above FC, likely resulting in water loss by deep percolation or runoff.

In 2010, the AIMM program was initiated on May 13 with TAW of greater than 90%. Precipitation was well above the 30-yr average in April, May, and June (Sub-section 6.3.1), and this caused very wet conditions at the site (Figure 6.11). The soils in both quarter sections were close to FC at the time of sampling on May 13 and AIMM predicted that the TAW remained high until the end of June (Figure 6.12). As a result, irrigation was not recommended during this period.

The AIMM output predicted that TAW had reached 70 and 68% TAW in the west and east quarter sections, respectively, in early July 2010 (Figure 6.12). However, soil samples collected on July 13 showed that the soil moisture content was at 100 and 78% TAW, respectively. As a result, the model was re-adjusted using the actual soil moisture values (Table 6.3, Figure 6.12). Based on the output from AIMM, only one irrigation event occurred on each quarter section in 2010. The west quarter section was irrigated from July 22 to 25, with 16 mm applied twice. The east quarter section was irrigated from July 16 to 23, with 2.5 pivot rotations of 27 mm of irrigation water applied per rotation.

At the end of July 2010, the AIMM output on the west quarter section indicated soil moisture was depleted by 5 to 6 mm d^{-1}, and that irrigation was required. Since the producer believed that the soil moisture was adequate and no irrigation was required, four soil moisture samples were collected on July 29. The results indicated that the TAW was at 100%, confirming that the soil moisture was a lot higher than predicted by AIMM. As a result, the model soil moisture was re-adjusted again (Table 6.3, Figure 6.12a). The rainfall event on August 1 generated some runoff at the edge-of-field water monitoring station, confirming that the soil was saturated. Results from soil moisture samples collected on August 6 and 10 from the east and west quarter sections, respectively, showed that no further irrigation was required before harvest.

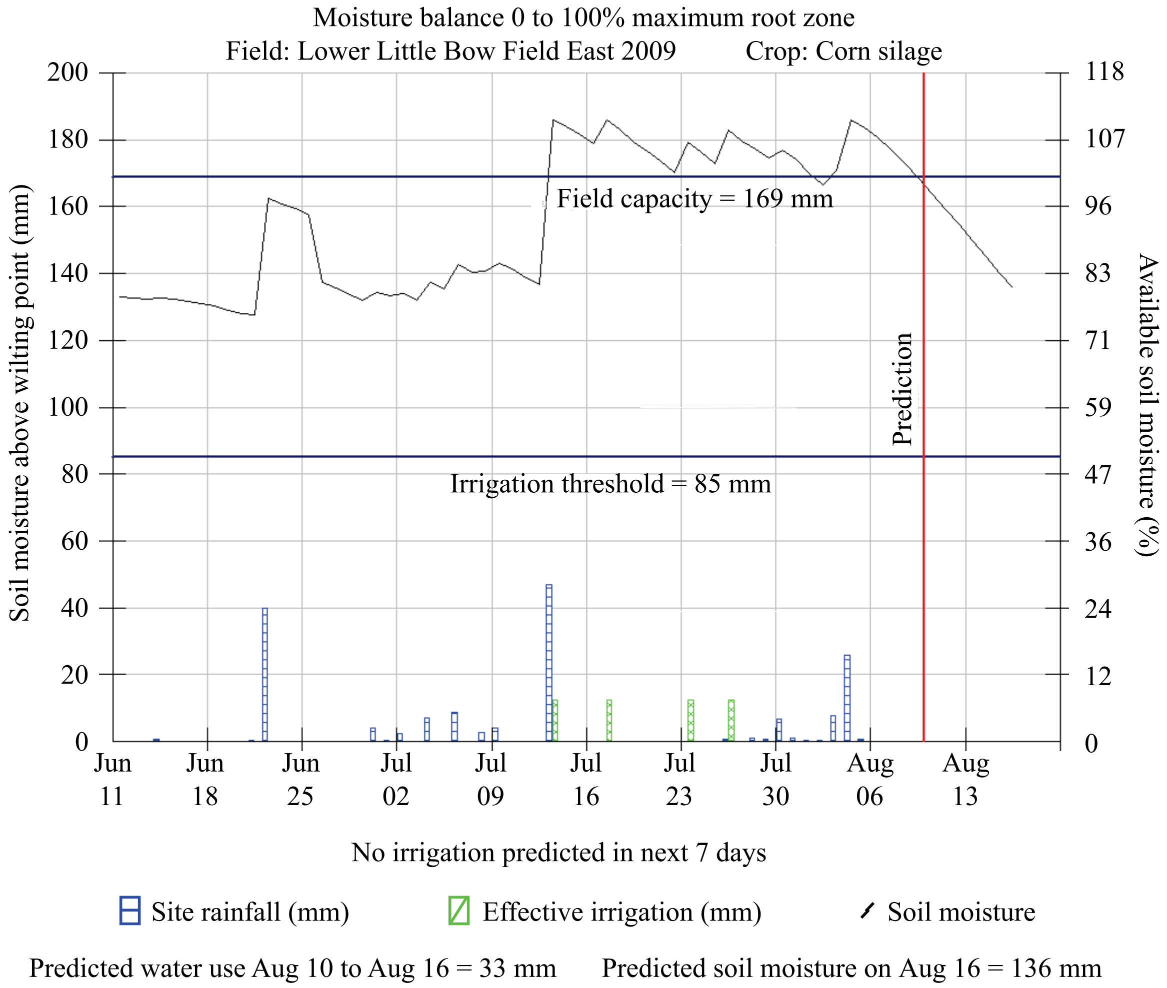

Figure 6.10. Alberta Irrigation Management Model output for the east quarter section at the Lower Little Bow Field on August 10, 2009.

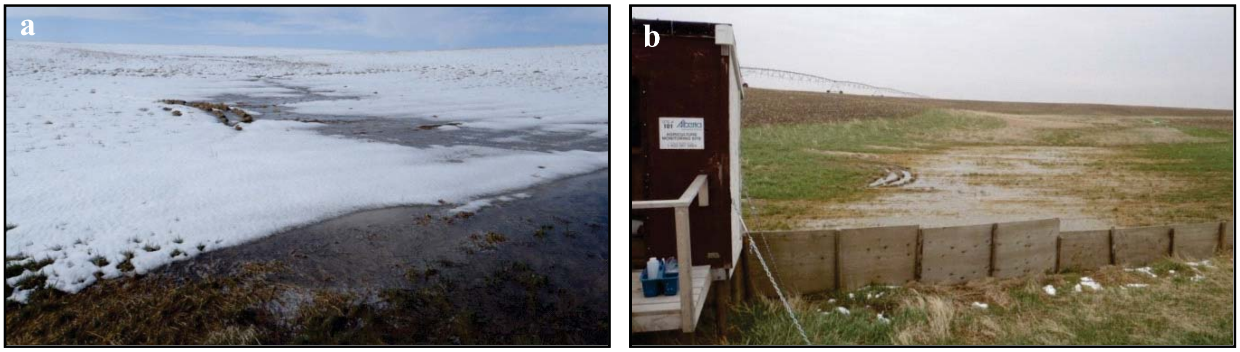

Figure 6.11. Runoff at the Lower Little Bow Field on (a) April 16 and (b) May 7, 2010.

In 2011, the AIMM program was initiated on June 1, with TAW at about 85% (Figure 6.13). Soils were saturated from the abundant spring precipitation until early July (Sub-section 6.3.1). From July 1 to August 29, 11 pivot rotations of water were applied. Runoff was generated when rain fell on July 12 and 13 immediately after the second pivot rotation. For the rest of the season, the soil moisture was maintained in the desirable range for crop development through efficient irrigation management (Figure 6.13). Soil moisture samples were collected on July 18 to determine the actual TAW. The model output was not adjusted since the measured TAW was comparable to the AIMM output. In 2011, the AIMM was effectively used by the producer as a tool to schedule the irrigation and the available soil moisture was maintained above 70% and less than field capacity. This soil moisture should have been appropriate to prevent irrigation runoff, but irrigation runoff was observed in late July and August 2011. However, this was mainly a localized issue caused by the irrigation pivot malfunction on July 21 when it became stuck near the drainage channel (Sub-section 6.3.6).

The AIMM program was partially effective in predicting soil moisture and it was only effective or successful for irrigation management at this site in 2011. In 2009 and 2011, soil moisture was reasonably well predicted, but this was not the case in 2010 because of very wet conditions and possible contributions from subsurface water. The AIMM program is not designed to account for subsurface water contributions to the root zone.

The first year that AIMM was used, 2009, the irrigator did not trust the results of the program and in spite of the AIMM recommendations of no irrigation, irrigation water was still applied. The reasons that this irrigator did not follow the model recommendations was related to past irrigation practices that relied more on anticipation of field crop water requirements and risk management. When soil moisture is less than 50%, the crop may become stressed and yield can potentially be reduced. Risks that must be considered by irrigators include potential equipment failure and labour shortages. If soil moisture decreases well below 50% TAW, restoring soil moisture can be a challenge, particularly during periods of high water demand. In 2010, the mistrust was not unfounded considering AIMM failed to accurately predict soil moisture. However, in 2011, the producer acknowledged appreciating the AIMM output and used the results to make decisions on irrigation scheduling. The result was well maintained soil moisture during the growing season in 2011.

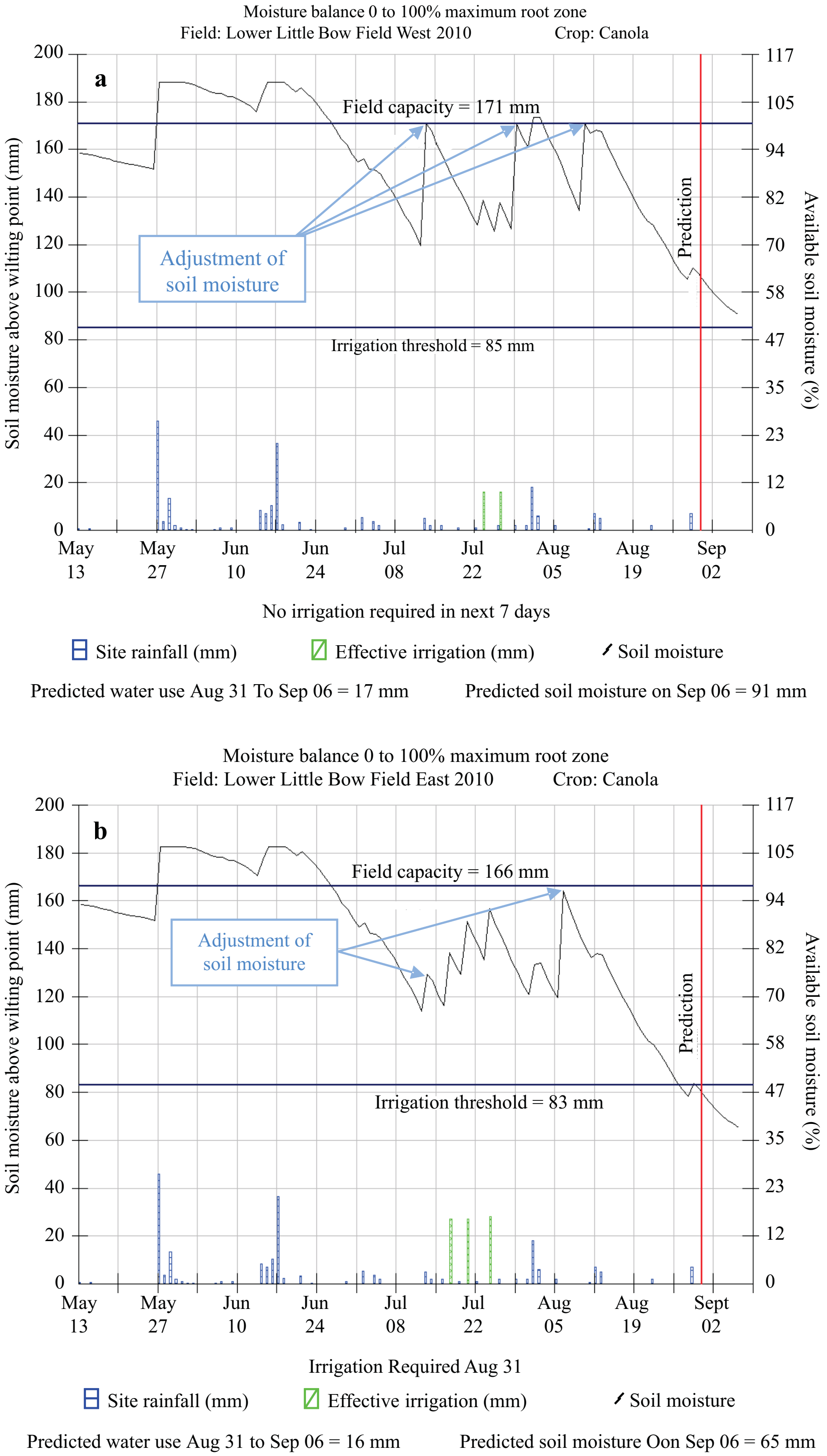

Figure 6.12. Alberta Irrigation Management Model output for (a) west (b) and east quarter sections at the Lower Little Bow Field in 2010.

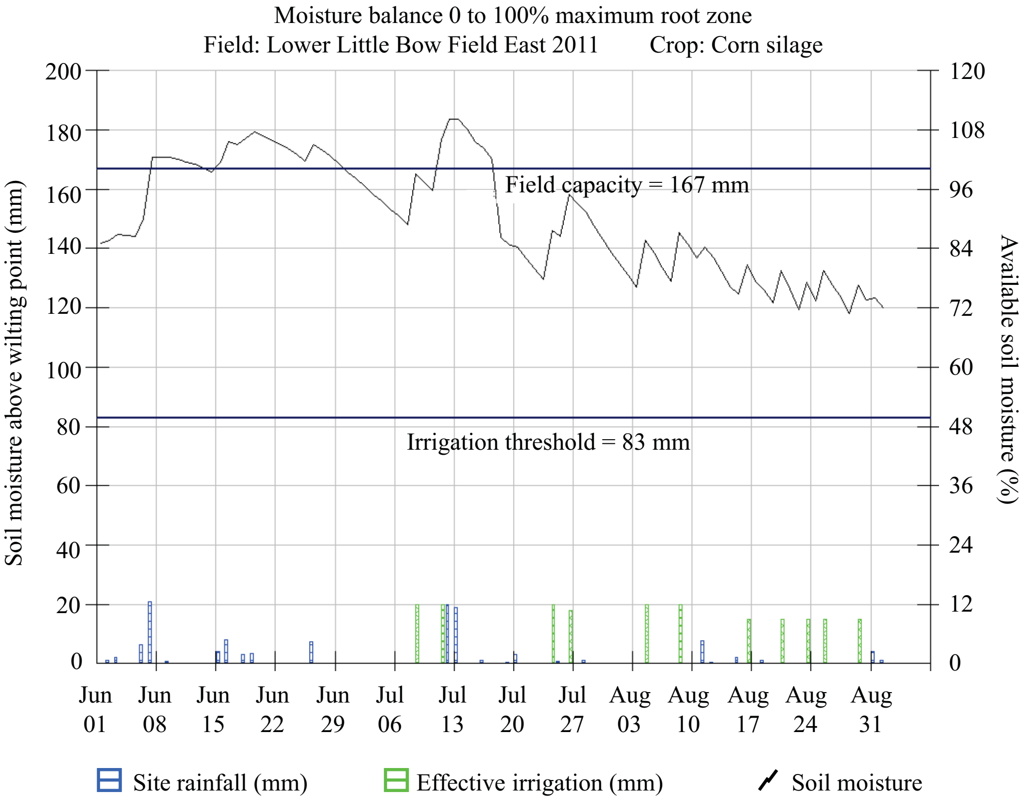

Figure 6.13. Alberta Irrigation Management Model output for the east quarter section at the Lower Little Bow Field in 2011.

The AIMM program has some value in minimizing runoff from irrigation application. If irrigation is carried out when soil moisture is near 50% TAW, the risk of runoff from irrigation is likely minimal. To achieve this, an irrigator would have to follow the recommendation from AIMM of when to irrigate. There may be some reluctance to allow soil moisture to be depleted too much to avoid runoff and run the risk of further soil moisture depletion if irrigation was delayed due to equipment failure or other unforeseen circumstances. The risk of runoff may also increase if AIMM underestimates soil moisture, as was observed at the LLB site in 2010. Groundwater discharge or high water tables may interfere in the capability of AIMM to predict soil moisture. If irrigation is carried out when soil is near or above FC, the risk of runoff will increase. The AIMM program was designed for irrigation scheduling and management, and to achieve maximum crop production.

As discussed for the Battersea Drain Field site (Section 5), it was not established whether or not over irrigation occurred during the pre-BMP period at the LLB site. Assuming that over irrigation did occur during the pre-BMP period is likely not valid as Nitschelm et al. (2011) showed that irrigators typically do not over irrigate in southern Alberta. Also, rainfall events shortly have irrigation increases the risk of runoff, and this cannot be prevented by using AIMM.

6.3.6 Pivot Irrigation System Modification BMP

The quantity of irrigation water applied annually to the field during the study varied from 62 to 230 mm depending on the crop type, precipitation, and irrigation management (Table 6.9). The lowest irrigation volume, applied in 2010, was attributed to above average precipitation. Precipitation was 30% above normal during the growing season (May to September) in 2010 (Table 5.4).

During normal operation, the pivot system water application rate was about 50 L s^{-1} when the system was between corners and about 60 L s^{-1} when the corner arm was in operation (Figure 6.14). The irrigation rate over the drainage channel was reduced from approximately 50 L s^{-1} in the pre-BMP period to approximately 25 L s^{-1} during the post-BMP (Figures 6.14 and 6.15). The time when the end sprinklers were turned off over the channel represented about 4% of a completed pivot rotation. This only reduced the total irrigation volume by about 2%, however. In terms of annual total volume of water applied, this small reduction was not observable because of other factors that govern annual variation in irrigation volume, such as precipitation (Table 6.9).

The pivot system modification BMP did not always work as planned. In 2009, the control panel was calibrated and the pivot valves were operational by July 23. However, irrigation runoff was still observed after the BMP implementation. Part of this was attributed to a misalignment of the area where the nozzles were turned off relative to the drainage channel. Because of the irrigation flow meter datalogger malfunction, daily irrigation flow could not be recorded in 2009. However, of the total runoff volume that occurred in 2009, about 54% was from rainfall and 22% was from irrigation (Table 6.8).

Table 6.9. Annual timing and volume of irrigation water applied to the east quarter section of the Lower Little Bow Field.

Year	Crop	First application date	Last application date	Irrigation volume (m^3 yr^{-1})	Growing season precipitation[z] (mm)	Irrigation amount (mm yr^{-1})
2007	Corn	Jun. 26	Aug. 7	124,823	136	224
2008	Canola/barley	Jun. 26	Jul. 22	100,472	322	181
2009	Corn	Jun. 4	Sep. 28	127,926[y]	240	230
2010	Canola/barley	Jul. 16	Jul. 23	34,512	292	62
2011	Corn	Jul. 1	Aug. 29	119,670	212	215

[z] May 1 to September 30.

[y] Estimated value. Total measured volume was 94,511 m^3 on July 20, after which the flow meter failed to record data. It was estimated that four more irrigation pivot rotations of 15 mm per rotation were added from July 20 to September 28.

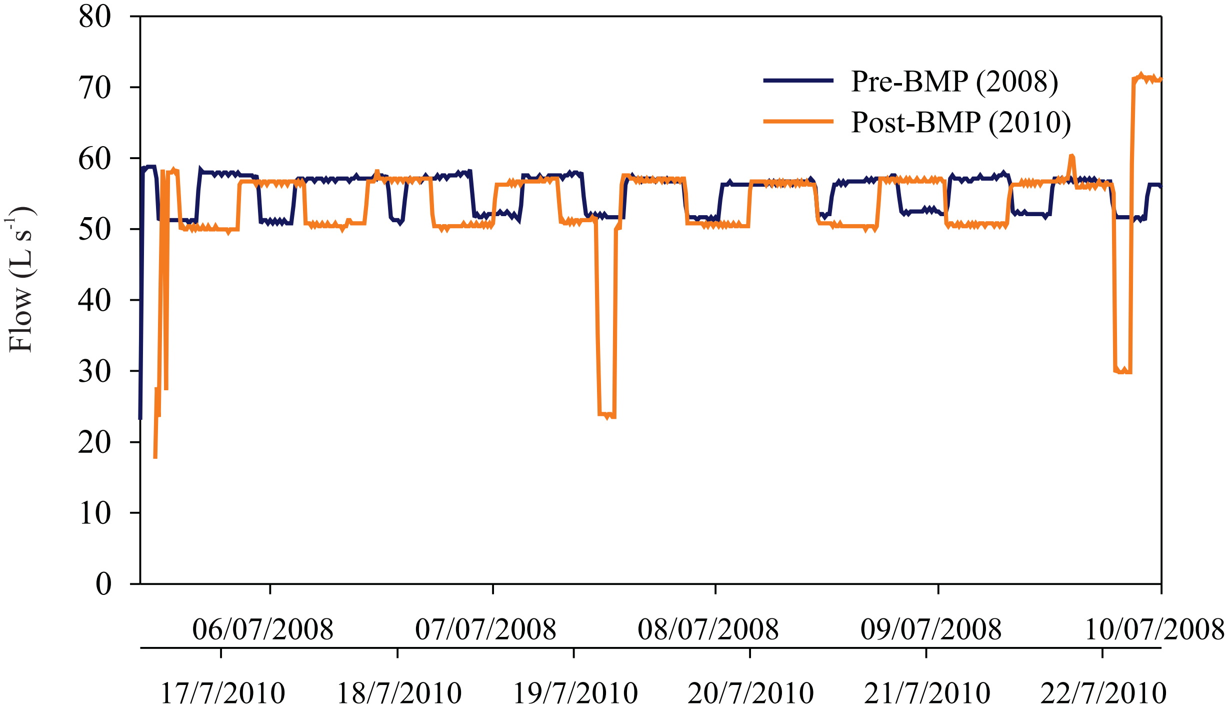

Figure 6.14. Pre- (2008) and post- (2010) BMP water flow through the pivot system at the Lower Little Bow Field. Reduced flow over the drainage channel can be observed in 2010.

In 2010, programming of the control panel was adjusted so that the timing of the sprinkler shut-off was better aligned with the drainage channel. The total area not irrigated remained the same as in 2009. The BMP worked very well since no runoff was generated by irrigation in 2010 (Table 6.9). However, less irrigation occurred in 2010 compared to the other years because it was a relatively wet year. The total volume of irrigation applied in 2010 was 34,512 m^3 of water, which was 66% less compared to the annual average (Table 6.9).

Irrigation runoff was not reduced in 2011. On July 21, the pivot system became stuck near the drainage channel. The pivot continued to irrigate for more than 18 h and this generated runoff in the channel, in the road ditch, and on the road (Figure 6.16a). The channel became saturated and remained very wet for an extended period, contributing to subsequent irrigation runoff. Futhermore, when the pivot become stuck, the control panel was no longer synchronized and the producer was unable to re-set the panel to turn off the sprinklers in the proper location. Therefore, this BMP was not implemented for the majority of the 2011 irrigation season.

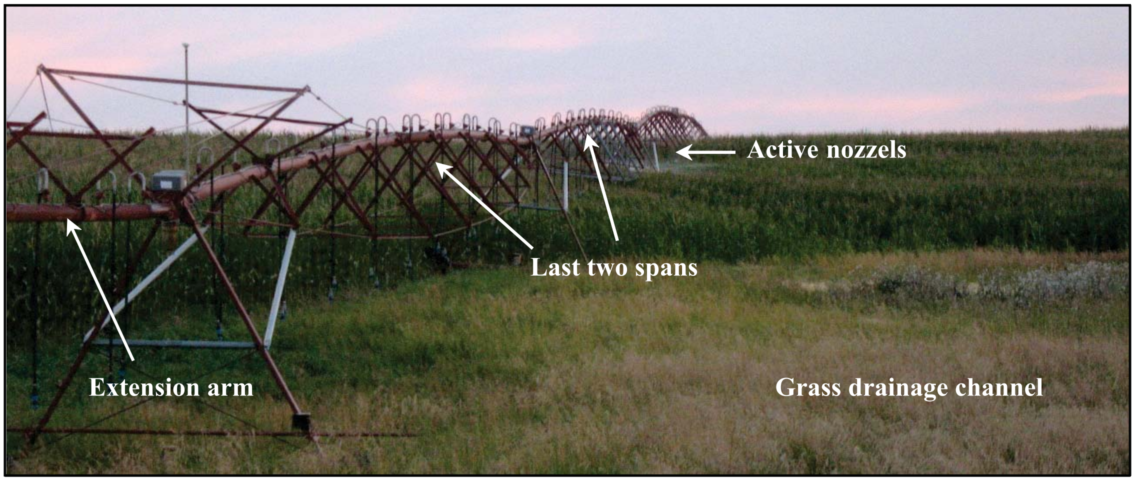

Figure 6.15. Pivot irrigation system at the Lower Little Bow Field showing the last two spans and the extension arm with nozzles turned off as the pivot exits from the drainage channel.

The total volume of applied irrigation water that was lost as runoff ranged from 0 to 10.6% from 2007 to 2011 (Table 6.10). The average loss in the pre-BMP period (2007 and 2008) was 4% compared to about 2% in 2009 and 2010 (post-BMP). The highest loss of 10.6% in 2011 was attributed to the pivot getting stuck near the drainage channel and continued to apply water for an extended period of time. For the assessment of this BMP, 2011 can be ignored and we can likely assume if the pivot did not become stuck, the BMP may have performed similar to 2010.

The total volume of irrigation runoff during the pre-BMP monitored years at this site (2003 to 2005, 2007, and 2008), represented about 40% of the total runoff volume (Table 6.8). In 2009 and 2010, about 9% of total runoff was due to irrigation, with no irrigation runoff in 2010. Of the 8 yr this site was monitored for surface runoff, 2010 was the only year that no runoff was generated by irrigation. It would appear that this BMP is effective when proper implementation can be achieved, such as in 2010. The results also suggest that the runoff loss from irrigation was restricted to a relatively small contributing area of the field. By preventing irrigation on only a small area (<2 ha) near the drainage outlet, runoff was reduced or prevented at this site.

6.3.7 Cost of Beneficial Management Practices

Several factors contributed to the cost associated with BMP implementation at the LLB site. Manure was not applied in the fall at the site from 2008 to 2011 as part of the BMP plan. Instead, manure was applied on alternate fields. In fall 2008 and fall 2010 manure was applied to an alternate field that was 6 km further from the feedlot than the LLB site. The additional hauling distance resulted in a \$30,000 yr^{-1} increase in transportation costs for these two years (Table 6.11). In 2009 and 2011, manure was applied to alternate fields that were about the same distance from the feedlot as the LLB site. Therefore, no net increase in hauling costs occurred in 2009 and 2011. In 2009, a new irrigation control panel and shut-off control valves were purchased and installed for the irrigation management BMP. Seeding of the grass channel incurred equipment rental and labour costs to the total cost. The overall cost for the BMPs was nearly \$76,700, of which 78% was needed for hauling manure a further distance for 2 yr.

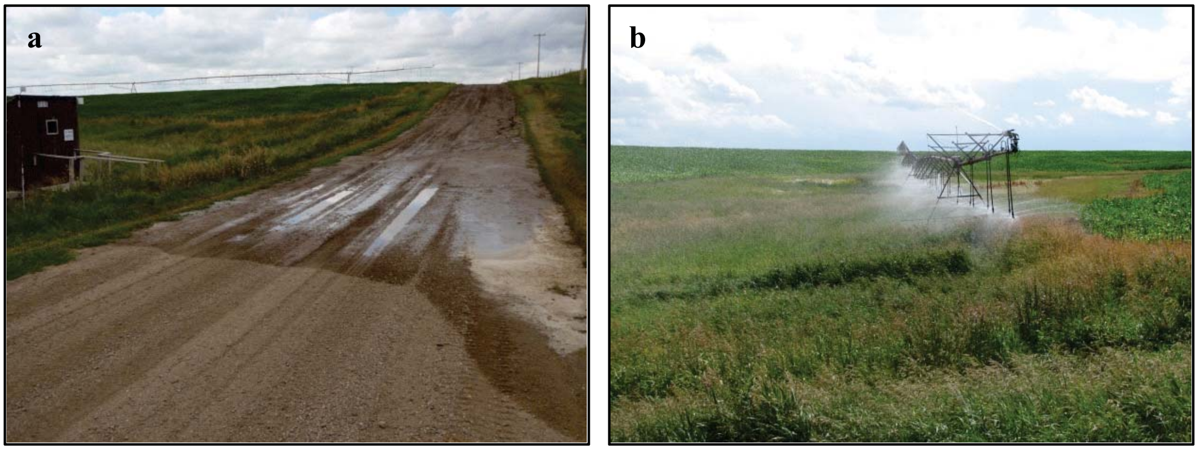

Figure 6.16. Irrigation system malfunction (a) generating runoff on the road on July 21, 2011 and (b) irrigating over the drainage channel on July 27, 2011.

Table 6.10. The amount of annual irrigation runoff relative to the amount of irrigated water applied at the Lower Little Bow Field from 2007 to 2011.

	2007	2008	2009	2010	2011
Annual water volume irrigated ($\mathrm{m}^3\ \mathrm{yr}^{-1}$)^z	124,823	100,472	127,926	34,512	119,670
Annual irrigation runoff ($\mathrm{m}^3\ \mathrm{yr}^{-1}$)	1,082	6,952	4,451	0	12,688
Applied water lost as runoff (%)	0.9	6.9	3.5	0	10.6

^{z} Volume irrigated on the east quarter section only.

Table 6.11. Cost of beneficial management practices at the Lower Little Bow Field.

Year	Item	Cost ($)	Labour (h)
2008	Soil testing	530	4
	Further distance for manure hauling	30,000	
	Sub-total	**30,530**	**4**
2009	Soil testing	530	4
	Fertilizer	0	
	Neutron probe access tube (3)	15	
	Rain gauges (3)	45	
	Control panel for pivot	7,625	
	Control panel installation	720	
	Aquamatic shut-off and solenoid valves (45)	3,105	
	Installation of valves	2,250	
	Grass seed (two, 25-kg bags)	410	
	Seeder and tractor rental ($100/h at 4 h)	400	
	BMP labour (grass seeding)	-	8
	Further distance for manure hauling	0	
	BMP maintenance and management[z]	-	4
	Sub-total	**15,100**	**16**
2010	Soil testing	530	4
	Fertilizer	0	
	Further distance for manure hauling	30,000	
	BMP maintenance and management[z]	-	8
	Sub-total	**30,530**	**12**
2011	Soil testing	530	4
	Fertilizer	0	
	Further distance for manure hauling	0	
	BMP maintenance and management[z]	-	8
	Sub-total	**530**	**12**
	Grand total	**76,690**	**44**

[z] Includes running AIMM and developing a nutrient management plan.

6.3.8 Water Quality

6.3.8.1 Runoff Water Quality

On average, nutrient concentration in runoff was generally higher in 2008 than in 2007, 2009, 2010, and 2011, with the exception of NO_3-N concentration, which was highest in 2011 (Table 6.12). The higher concentration in 2008 was likely due to the manure application frequency in the east quarter section. The whole east quarter section, which contained the drainage channel and monitoring station, received manure in fall 2007 and then no manure was applied from 2008 to 2011 as part of the BMP plan. Prior to 2007, manure application to the entire east quarter section occurred in fall 2004, though some manure was applied on high points in the field in 2005 (Little et al. 2006).

There was no consistent trend in water quality parameter concentrations among snowmelt, rainfall, and irrigation runoff events. Runoff event types varied according to parameter and year (Table 6.12). For example, rainfall runoff nutrient concentrations were generally higher than irrigation runoff concentrations in 2007, 2008, and 2011. Snowmelt nutrient concentrations were higher than irrigation and rainfall runoff concentrations in 2009 and 2011, but generally not in 2010. In 2010, the concentrations of most parameters were higher in rainfall compared to snowmelt, except for the P parameters. The lower nutrient concentrations generally observed in the irrigation runoff compared to snowmelt and rainfall may suggest a fairly localized contributing area during irrigation events.

Overall, the majority of TN was generally in the organic form, except in 2011 (Table 6.12). Nitrate-N and TN concentrations mimicked each other and fluctuated to the largest degree in 2008 and 2011 compared to other years (Figure 6.17a). Ammonia-N generally remained less than 3 mg L^{-1}. High concentrations of NO_3-N in 2010 and 2011 were attributed to extended periods of high precipitation. This effect was seen at a number of our BMP sites in this study. Organic N varied less than NO_3-N throughout the study, with highest concentrations in the pre-BMP period in May and June 2008.

Total P in runoff was mainly composed of 71 to 97% TDP for all event types and years (Table 6.12). There was a gradual trend of decreasing TP and TDP concentrations from 2008 to 2010 (Figure 6.17b). Total suspended solids concentration was generally less than 200 mg L^{-1}, except in 2009 when TSS concentration was more variable and ranged from 3 to 2040 mg L^{-1} (Figure 6.17c). The high TSS and PP concentrations were likely the result of the disturbance caused by seeding and re-seeding grass in the drainage channel in 2009.

The Cl concentrations were higher in rainfall runoff than in snowmelt or irrigation runoff and the highest concentrations occurred during rainfall in the wetter years of 2010 and 2011 (Table 6.12). *Escherichia coli* concentrations were higher in the summer months and were highest in 2008 and 2009 (Table 6.12). Electrical conductivity (EC) was higher in rainfall runoff compared to irrigation runoff and snowmelt runoff events.

Table 6.12. Average concentration of runoff water quality parameters measured at the Lower Little Bow Field from 2007 to 2011.[z]

		TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl[x]	*E. coli*	EC	
Event[y]	n	----------	----------	----------	----------	(mg L^{-1})	----------	----------	----------	----------	(mpn 100 mL^{-1})	(µS cm^{-1})	pH
							2007						
Rain	1	8.53	5.43	2.85	0.17	2.17	2.07	0.10	38	n/a	1	6600	8.20
Irrig[w]	4	4.49	4.34	0.06	0.06	1.55	1.36	0.19	53	n/a	2248	3420	8.58
All	5	5.30	4.56	0.62	0.09	1.67	1.50	0.17	50	n/a	1799	4056	8.50
							2008						
Rain	14	14.47	6.90	6.58	0.63	3.92	3.74	0.18	38	47 (2)	1319	3963	8.19
Irrig	8	6.67	5.38	0.83	0.23	3.23	2.89	0.33	38	36 (1)	5613	2719	8.16
All	22	11.63	6.35	4.49	0.48	3.67	3.43	0.24	38	44 (3)	2881	3511	8.18
							2009						
Snow	12	6.90	3.41	1.90	1.34	3.22	3.05	0.17	20	40	16	1929	7.97
Rain	5	4.57	3.05	1.43	0.05	2.48	2.16	0.32	150	50	1486	2155	8.18
Irrig	11	3.76	2.72	0.74	0.22	2.75	1.96	0.79	523	32	4014	1552	8.15
All	28	5.42	3.14	1.51	0.63	2.84	2.50	0.34	161	42	1307	1951	8.09
							2010						
Snow	12	5.19	2.71	2.06	0.33	2.14	2.03	0.11	7	42	68	1771	7.98
Rain	23	6.52	3.58	2.11	0.69	1.32	1.24	0.08	8	123	36	3865	8.40
All	35	6.07	3.28	2.09	0.57	1.60	1.51	0.09	7	95	47	3147	8.25
							2011						
Snow	10	18.76	3.10	14.94	0.51	2.61	2.43	0.18	36	66	21	1922	7.78
Rain	10	9.31	4.47	4.76	0.07	2.17	2.10	0.07	45	101	240	3814	8.05
Irrig	6	3.10	2.69	0.34	0.06	1.36	1.28	0.08	10	33	2081	1847	8.15
All	26	11.51	3.53	7.65	0.24	2.15	2.04	0.12	34	72	580	2632	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] Runoff types: Snow = snowmelt, Rain = rainfall, Irrig = irrigation, All = all runoff types combined.

[x] This water quality parameter was not added until late July, 2008 (number of samples shown in parentheses).

[w] The irrigation sample collected on July 27, 2007 was omitted because there was not enough sample for all nitrogen, phosphorus, microbial, and EC analyses.

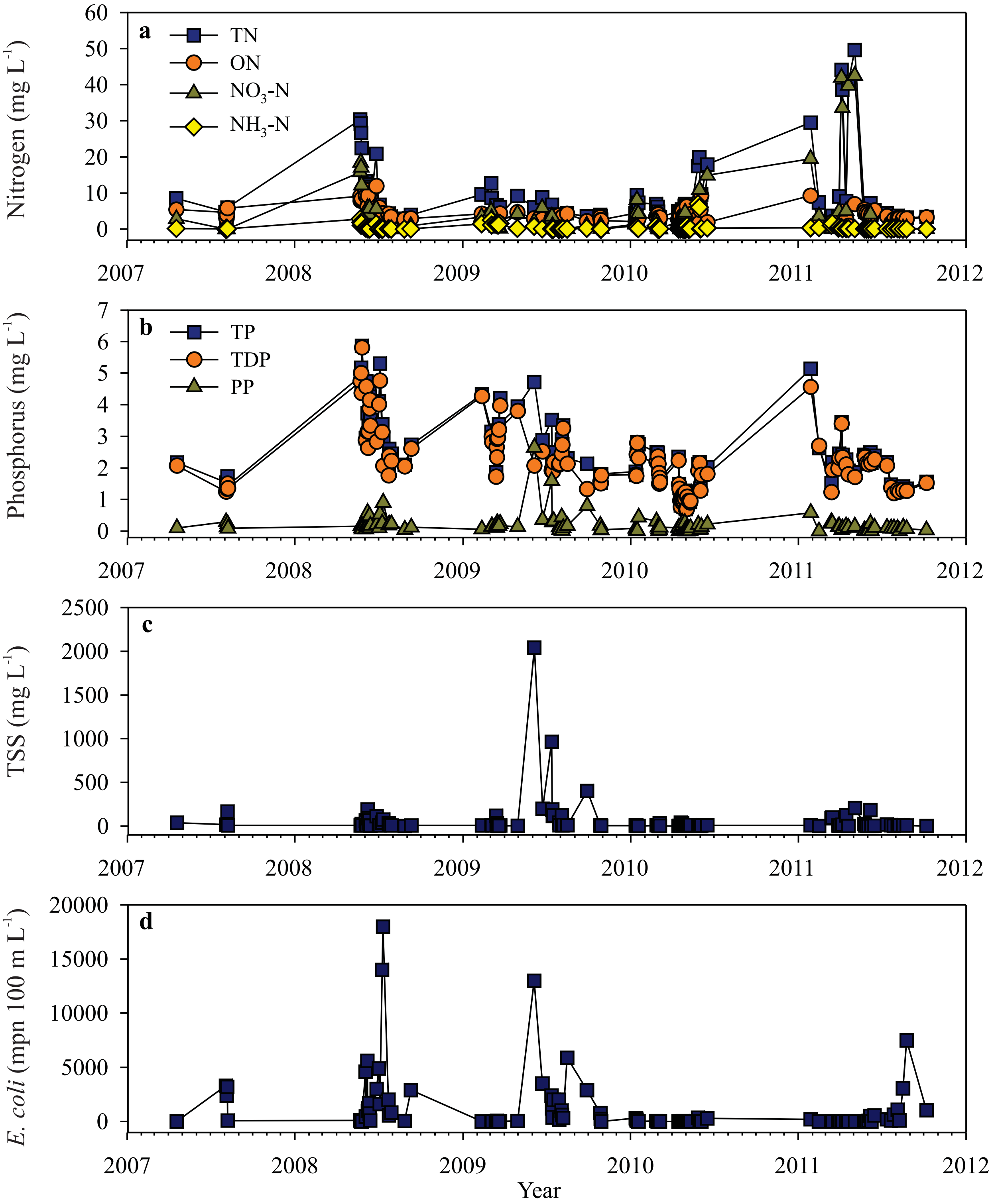

Figure 6.17. Concentration values for (a) total nitrogen (TN), organic nitrogen (ON), nitrate nitrogen (NO_3-N), and ammonia nitrogen (NH_3-N); (b) total phosphorus (TP), total dissolved phosphorus (TDP), and particulate phosphorus (PP); (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) at the Lower Little Bow Field from 2007 to 2011.

The export loads of nutrients and sediment were lowest in 2007. Total loads in 2007 were 0.03 to 59% of the loads in 2008 to 2011, depending on the parameter (Table 6.13). Total runoff volume in 2007 was only 3 to 9% of the volumes measured in the other 4 yr (Table 6.8) and this was largely responsible for the smaller loads in 2007. The average annual loads in the post-BMP period (2009 to 2011) were 2 to 12 times the average annual loads in the pre-BMP period (2007 and 2008). Any potential load reduction due to BMP effects, such as reduced runoff or nutrient concentrations from the irrigation or nutrient BMPs was likely masked by the much larger runoff volumes in the post-BMP period.

Loads were the largest in 2011 for TN, ON, NO_3-N, TP, and TDP, and this was caused mainly by larger snowmelt and irrigation runoff volumes compared to the previous 4 yr. Organic N, TP, and TDP loads were similar in 2008, 2009, and 2010, even though the runoff volumes were greater in 2010. Particulate P and TSS loads were greater in 2009 compared to 2010 and 2011, and this was due to the larger concentrations in 2009 (Table 6.12).

6.3.8.2 Beneficial Management Practice Effects on Water Quality

As outlined in the methods, the 2009 water quality data were not included in the statistical analysis between the pre- and post-BMP periods. When the 2009 data were included, the concentrations of PP and TSS were significantly higher in the post-BMP period compared to the pre-BMP period (data not shown). This was the unintentional consequence when the grass channel was accidently sprayed with herbicide and the channel had to be tilled and re-seeded in early summer 2009. This caused an increase in sediment loss, which was the opposite effect intended of the established grass cover had it not been disrupted. Therefore, it was decided that the 2010 and 2011 data better represented the post-BMP period.

Several water quality parameters (TN, ON, NO_3-N, TP, TDP, PP, and TSS) were significantly reduced in concentration from the pre-BMP period to the post-BMP period for rainfall and irrigation runoff (Table 6.14). This could not be determined for snowmelt because no pre-BMP snowmelt runoff samples were obtained at this site. Several parameters (TN, ON, NO_3-N, TP, TDP, PP, TSS, and *E. coli*) were also significantly reduced in the post-BMP period when the irrigation and rainfall runoff were combined (i.e., growing season). Electrical conductivity was not significantly different between the two periods, but tended to be less in the post-BMP period

Table 6.13. Annual loads of nutrients and total suspended solids in runoff at the Lower Little Bow Field from 2007 to 2011.

Year	TN[z]	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
	------------------	------------------	------------------	(kg yr^{-1})	------------------	------------------	------------------	------------------
2007	4.15	3.96	0.11	0.05	1.74	1.53	0.21	102
2008	103	63.4	33.8	3.43	42.2	38.0	4.18	401
2009	98.1	60.1	29.1	7.19	50.5	46.1	4.37	1905
2010	318	65.2	195	44.1	50.4	46.9	3.43	174
2011	535	113	410	10.0	81.6	77.7	3.89	923

[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.

Table 6.14. Average water quality parameter concentrations during the pre-BMP (2007 to 2008) and post-BMP (2009 to 2011) periods at the Lower Little Bow Field.[z,y]

		TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	*E. coli*	EC	
Period[x]	n	----------	----------	----------	----------	(mg L^{-1})	----------	----------	----------	(mpn 100 mL^{-1})	(µS cm^{-1})	pH
						Rainfall						
Pre-BMP[w]	15	14.1*a*	6.81*a*	6.33*a*	0.60*a*	3.81*a*	3.63*a*	0.18*a*	38*a*	1231*a*	4139	8.19
Post-BMP	33	7.37*b*	3.85*b*	2.91*b*	0.50*b*	1.58*b*	1.50*b*	0.08*b*	19*b*	98*b*	3850	8.29
						Irrigation[v]						
Pre-BMP	12	5.94*a*	5.03*a*	0.57*a*	0.17	2.67*a*	2.38*a*	0.28*a*	43*a*	4491	2953	8.30
Post-BMP	6	3.10*b*	2.69*b*	0.34*b*	0.06	1.36*b*	1.28*b*	0.08*b*	10*b*	2081	1847	8.15
						Growing season[u]						
Pre-BMP	27	10.5*a*	6.02*a*	3.77*a*	0.41	3.30*a*	3.07*a*	0.22*a*	40*b*	2680*a*	3612	8.24
Post-BMP	39	6.71*b*	3.67*b*	2.52*b*	0.44	1.54*b*	1.46*b*	0.08*b*	18*a*	403*b*	3542	8.27

[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] Snowmelt data were nor included because there was no snowmelt in the pre-BMP period. The 2009 data were excluded from statistical analysis because the grass channel was tilled and re-seeded in early July 2009 and this caused an increase in sediment loss.

[x] The pre-BMP period included data from April 7, 2007 to September 10, 2008. The post-BMP period included data from June 5, 2009 until October 7, 2011. No snowmelt runoff occurred during the pre-BMP period.

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

[v] No irrigation runoff occurred in 2010.

[u] Growing season average concentrations include rainfall and irrigation runoff events.

compared to the pre-BMP period. Groundwater discharge observed in the drainage channel during the post-BMP period may have had some influence on runoff water quality, but we suspect that this was minor.

The above results suggest that the BMPs applied at this site improved runoff water quality. The cessation of manure application and nutrient management targeted nutrient source factors, with a focus on high STP concentration. Soil sample analysis was used to monitor the nutrient source. Extractable soil NH_4-N was significantly reduced after cessation of manure application (Table 6.4) and this was reflected in lower NH_3-N concentration in runoff during the post-BMP period. The soil-to-runoff effect was less clear for NO_3-N. Even though NO_3-N in runoff was reduced by more than 33%, there was no clear trend in soil extractable NO_3-N concentration, nor was it significantly reduced during the post-BMP period. After manure was applied in fall 2007, STP concentration significantly increased in 2008 and then significantly decreased to a similar concentration before the manure application in 2007. Concentrations of TDP and TP in rainfall and irrigation runoff followed the same trend and were significantly less in the post-BMP period. After manure is applied to the land, time is required for P in manure to interact and equilibrate with soil. Prior to this equilibration period, P from freshly or recently (i.e., within a few months) applied manure is generally more prone to loss through runoff. Even though soil NO_3-N and STP did not decrease after manure application ceased, without the applications of fresh manure, the residual nutrients near the soil surface (i.e., within 1 to 2 cm) likely became more equilibrated with the soil and less prone to loss in runoff, particularly for STP.

Although a reduction in P loss in runoff was observed, the risk of P loss when runoff occurs is still high due to the high concentration of STP at this site. It is expected that the initial reduction of P in runoff will not continue at the same rate and that P concentration will level off and remain relatively high because of the high residual STP. At the LLB site in particular, Nolan et al. (2006) found a high degree of soil phosphorus saturation (DPS) that ranged from 59 to 68%. In the Netherlands, a DPS of 25% or more has been established as a critical value, above which the potential for P losses through runoff and leaching increases (Breeuwsma et al. 1995). Soil with high DPS and low P sorption capacity cannot retain much more P into its non-labile fraction as it becomes saturated. Therefore, the addition of P from the manure remains in the labile fraction and is more susceptible to losses. Casson et al. (2006) reported that Alberta soils with high DPS were more susceptible to P losses in runoff and leaching. Furthermore, DPS values from 25 to 40% for soil have been associated with greater P losses in surface and subsurface waters (Pautler and Sims 2000).

Overall, the concentration of *E. coli* was reduced by 85% in the post-BMP period compared to the pre-BMP period (Table 6.14). Since manure application was stopped after 2007, the bacteria in residual manure when exposed to sunlight, periodic drying of surface soil, and winter conditions, would be expected to decrease with time.

6.3.8.3 Soil and Water Phosphorus Relationship

Little et al. (2007) reported a linear relationship between STP and TP in runoff using 3 yr of data (2003 to 2005) from eight field-scale watersheds in Alberta, including the LLB site (Figure 6.18). The data points from the current study (2007 to 2011) clustered near the LLB site data points used in the linear relationship as determined by Little et al. (2007) (Figure 6.18). The cluster of points to the lower left in Figure 6.18 is for non-manured sites, which have relatively low STP concentrations, and the three points in the upper left are for a heavily manured site in central Alberta.

The data from this study tended to be below the STP vs. TP relationship found by Little et al. (2007) (Figure 6.18). In other words, in the current study, for a given STP concentration, TP concentration in runoff tended to be less compared to that of Little et al. (2007). Several factors may contribute to this difference. The concentration of TP was calculated as arithmetic means in the current study; whereas, Little et al. (2007) used flow-weighted mean concentration (FWMC). Also, soil sampling strategy was not the same between the two studies. Finally, the concentrations of water quality parameters may have been diluted by the larger volume of runoff during the post-BMP period (2009 to 2011) compared to the pre-BMP period (2007 and 2008) and to the Alberta Soil Phosphorus Limits Project (2003 to 2005) (Table 6.8).

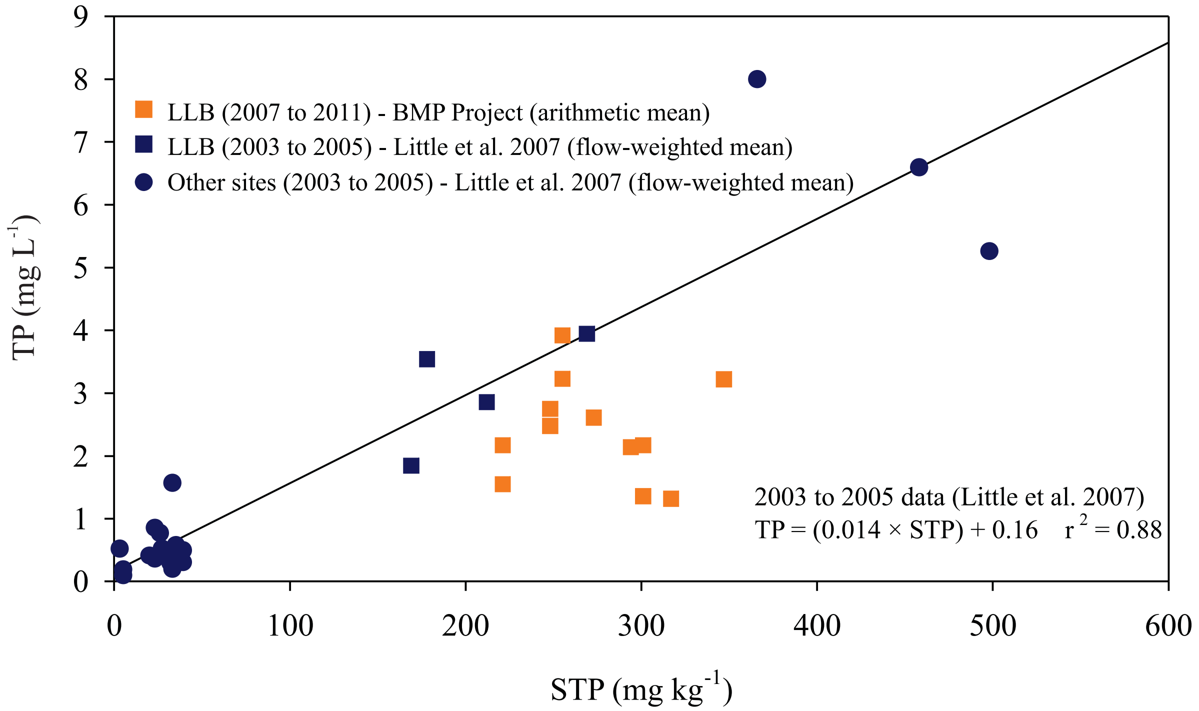

Figure 6.18. Soil-test phosphorus (STP) versus runoff total phosphorus (TP) at the Lower Little Bow Field from 2007 to 2011 compared to the relationship reported by Little et al. (2007) for 0- to 15-cm soil layer.

6.4 Conclusions

- The main water quality risk at the LLB site was excess nutrients in the soil from the application of cattle manure, with the loss of accumulated soil P in runoff being of primary concern. This supports the observations found at this site during the previous Alberta Soil Phosphorus Limits Project.

Overall BMP effect

- Water quality parameter concentrations, including TN, ON, NO_3-N, TP, TDP, PP, TSS, and *E. coli*, were significantly reduced by 33 to 85% from the pre- to the post-BMP period.
- Overall, average total P concentration in runoff was reduced from 3.3 to 1.5 mg L^{-1}, and average TN concentration was reduced from 10.5 to 6.7 mg L^{-1}.

Nutrient source

- The cessation of manure application caused a decrease in extractable soil NH_4-N concentration; whereas, extractable soil NO_3-N concentration was not appreciably affected during the 3-yr, post-BMP period. Soil-test P concentration increased following the last manure application in the pre-BMP period (2007) and then significantly decreased back to a level slightly higher than before the manure application. Therefore, STP concentration was not reduced from the pre-BMP period to the post-BMP period.
    - The cessation of manure application was successful in the improvement of runoff water quality. However, several more years without manure application, or any form of P, would be required to reduce STP concentration through crop removal to a more desirable level in order to minimize the loss of P to runoff water.

Nutrient transport

- The establishment of grass in the drainage channel was effective in reducing TSS and PP concentrations in rainfall runoff water. This suggests that grassed waterways may be effective in reducing erosion and/or trapping particulates in runoff.
    - Average TSS was reduced from 40 to 18 mg L^{-1}, and PP concentration was reduced from 0.22 to 0.08 mg L^{-1} between the pre-BMP period (i.e. 2007 and 2008) and post-buffer establishment (i.e. 2010 and 2011).
    - This BMP will likely be maintained by the producer because the area of the grass channel (2 ha) was relatively small and the area was not particularly productive for annual crops. Additionally, the area was at risk for field equipment to get stuck in wet years. Harvesting the channel for forage in the future may remove a small amount of nutrients, but because of the small size, harvesting may be impractical.
- The modification to the irrigation pivot system to prevent water application in the critical source area in the lower drainage channel by shutting off part of the pivot had the potential to reduce runoff caused by irrigation.
    - However, there were challenges with implementing the BMP. Due to technical difficulties in operating the modified pivot, this BMP was only successfully implemented in one out of three years. In the year of successful implementation, irrigation runoff was eliminated.
    - On average, 25% of the runoff from this site was from irrigation runoff. Under normal conditions at this site, 0 to 7% of the amount of water irrigated contributed to runoff. Therefore, preventing irrigation runoff from fields with similar runoff risks can reduce total runoff.

- The use of the AIMM program was generally successful in predicting soil water content, but was not always effectively used for irrigation management.
    - The tool can be used to optimize irrigation for crop yield, while at the same time prevent excess soil water and hence decreased runoff risk.
    - The irrigator at this site did not follow the AIMM model recommendations on several occasions. Irrigation water was applied in 2009 despite the high soil moisture content because of other management considerations. There were occasions when irrigation was not applied despite AIMM recommendations in 2010. The model predictions were inaccurate due to subsurface water contributions that year at the site. In 2011, the AIMM predictions were accurate and the recommendations were well followed.

Cost of BMPs

- The cost of the BMPs was nearly $76,700 during the post-BMP period, and was one of the most expensive among the BMP sites in the project.
    - The majority (78%) of the cost was for hauling manure greater distances (6 km) to alternate fields in two out of four years. For the other two years, the alternate fields were the same distance from the feedlot as the LLB site, resulting in no additional hauling costs in those years. Fortunately, the producer had nearby land where manure could be applied, and this kept the additional hauling costs to a minimum. Most of the remaining cost was for the modifications to the pivot irrigation system.
    - Continued practice of not applying manure will result in substantial additional costs for manure management on an annual or bi-annual basis, not to mention that the cost will increase the further the manure is hauled. The use of manure on other fields, which require nutrients for optimum crop growth, may reduce the use and cost for commercial fertilizers. However, the savings are unlikely to offset the increase in hauling costs.