SECTION 5
LOWER LITTLE BOW RIVER FIELD SITE

5.1 Introduction

The Lower Little Bow River Field (LLB) site includes two adjacent quarter sections of cropland approximately 30 km northeast of Lethbridge (N½8-12-19-W4) (Figure 5.1). The field is irrigated by two centre pivot irrigation systems, with the west pivot equipped with a corner arm. The site typically receives cattle manure from the producer's cattle feedlot located nearby. Because of repeated manure application, soil-test phosphorus (STP) is well above the agronomic level of 60 mg kg^{-1}. Soil-test P is in excess of 200 mg kg^{-1} at this site. Water quality of the runoff from the site contains elevated concentration of phosphorus (P), nitrogen (N), sediment, and bacteria. The site has been monitored since 2007. Beneficial management practices (BMPs) were implemented in 2009, and 2 yr of post-BMP monitoring (2009 and 2010) have been completed. Further details about the site are described in Olson and Kalischuk (2008, 2009, 2010).

5.2 Weather

5.2.1 Methods

The weather data were collected by different weather stations for different uses. A real-time automated weather station was required for the irrigation management BMP. The closest weather station was near Iron Springs, Alberta (latitude 49° 54' 2”, longitude 112° 44' 24", elevation 893 m) and is part of the Irrigation Management Climate Information Network (IMCIN). The weather station is also part of the Environment Canada climate data (Iron Springs, Agricultural Drought Monitoring; AGDM). Data from Iron Springs reported previously for 2007, 2008, and 2009 (Olson and Kalischuk 2008, 2009, 2010) were revised, and the revised values are presented in this report. The revised values were obtained from the AgroClimatic Information Services (ARD 2011b). The 30-yr average (1971 to 2000) values were obtained from the

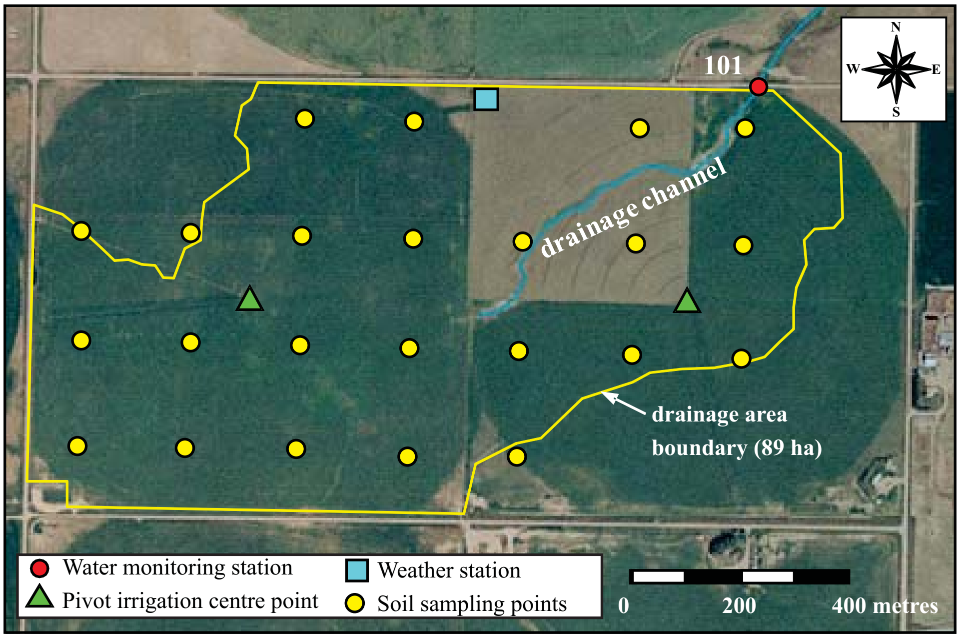

Figure 5.1. Lower Little Bow River Field site showing the drainage area, instrumentation, and the agronomic soil sampling points.

Lethbridge Canada Department of Agriculture (CDA) weather station (latitude 49° 41' 42”, longitude 112° 46' 3", elevation 910 m) because of the lack of historical data from the Iron Springs station (Environment Canada 2011).

For the modelling aspect of the BMP Evaluation Project, a weather station was installed in 2008 at the LLB site (Figure 5.1). The weather station was equipped to measure relative humidity, temperature, and precipitation as described in Olson and Kalischuk (2009, 2010).

5.2.2 Results and Discussion

Results from the Iron Springs weather station for 2010 have been reported for the LLB site in Sub-section 4.2.

The precipitation data collected in 2010 at the LLB site was generally similar to the Iron Springs weather station (Figure 5.2). One exception was in November when about twice as much precipitation was measured at the Iron Springs station compared to the LLB station. Other minor differences between the two weather stations may have been due to local spatial variations in precipitation.

5.3 Routine Management Activities in 2010

Spring conditions in 2010 were wet and seeding was delayed until May 20. The entire northeast quarter section was seeded to canola as well as the south half of the northwest quarter section. The north half was seeded to corn. As prescribed by the BMP, no manure or P fertilizer was applied. Nitrogen fertilizer was applied at a rate of 112 kg ha^{-1} of urea (46-0-0) on both quarter sections. On July 7, about one-third of the canola in the northwest quarter section was plowed with disks because of poor germination and growth. This area was re-seeded to barley on July 13. The canola was swathed on September 27 and harvested on October 13 and 14, with a yield of 2.9 Mg ha^{-1}. The corn was harvested for silage on October 14 and yielded 29.6 Mg ha^{-1}, and the barley was

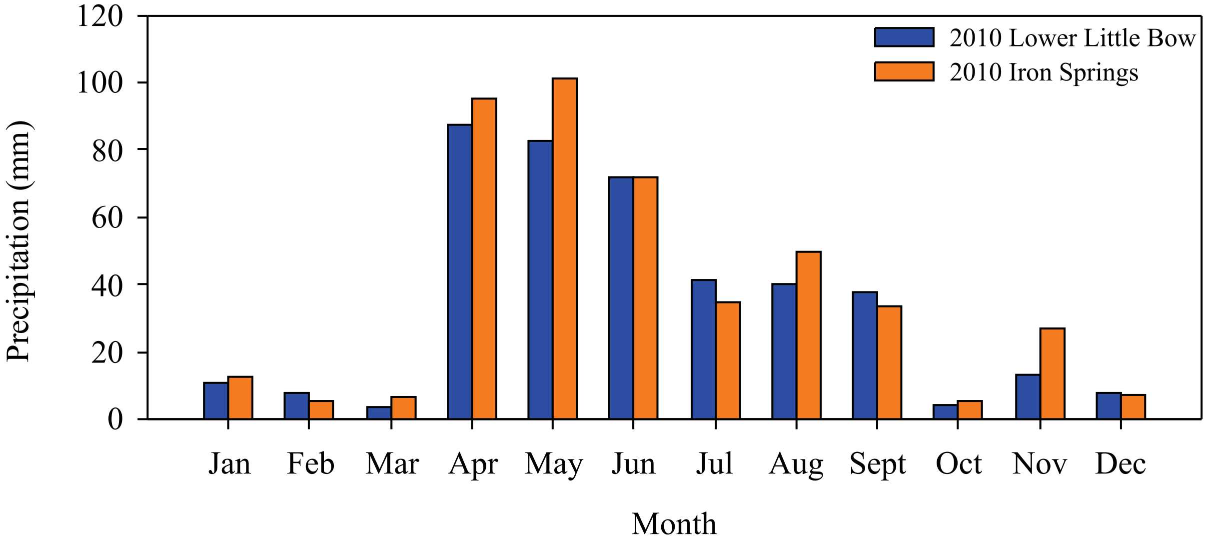

Figure 5.2. Total monthly precipitation from the Lower Little Bow River Field site and Iron Springs weather stations in 2010.

harvested for silage on September 20 and yielded a total of 100 Mg. The exact area seeded to barley was not known. However, if we could assume about 11 ha were seeded to barley, a yield estimate would be about 9 Mg ha^{-1}.

5.4 Beneficial Management Practices Activities in 2010

After 2 yr of pre-BMP monitoring (2007 and 2008), several BMPs were implemented in late 2008 and in 2009 including (1) development of a nutrient management plan, (2) establishment of a grass channel, and (3) improvement of irrigation management and runoff control. The second year of post-BMP monitoring was completed in 2010. The nutrient management plan included the cessation of manure application (i.e., no P addition) and to monitor the soil for fertilizer N requirements for crop growth.

5.4.1 Nutrient Management Plan

As in 2008 and 2009, no manure, or any form of P, was applied in 2010. The previous manure application was in October 2007. The manure that would have been applied in 2010 at the LLB site was transported to alternative fields managed by the same producer. Transportation and spreading of manure took place the week of October 10. Manure was applied to the same alternative field as used in 2008. The field was located about 7.5 km from the feedlot. The LLB site is less than 2 km from the feedlot. Therefore, the cost of hauling manure in 2010 was higher because of the further distance.

The nutrient management plan was developed for N fertilizer recommendations for 2010, and this was based on soil samples collect on October 26, 2009 as described in Olson and Kalischuk (2010). The Alberta Farm Fertilizer Information and Recommendation Manager (AFFIRM) program was used to determine fertilizer recommendations (AAFRD 2005b; Appendix 4). The original recommendation was for no N fertilizer application for both quarter sections based on barley (Olson and Kalischuk 2010). However, with canola as one of the crops in 2010, the recommendations were revised to 39 kg ha^{-1} N for the northeast quarter section and no N fertilizer for the northwest quarter section. The producer actually applied about 52 kg ha^{-1} of N (i.e., 112 kg ha^{-1} urea fertilizer).

5.4.2 Grass Channel

In spring and summer 2009, a grass waterway was established in the drainage channel of the northeast quarter section of the LLB site. The grass was already well established by spring 2010 (Figures 5.3 and 5.4). The grass channel was not harvested in 2010. The grass could be used for forage but the access was limited because of wet soil for most of the season (Figure 5.3).

5.4.3 Irrigation Management

The irrigation management BMP included two components: the pivot irrigation system modification and use of the Alberta Irrigation Management Model (AIMM) for irrigation scheduling.

5.4.3.1 Pivot Irrigation System Modification

During the pre-BMP period, it was observed that irrigation was often responsible for the largest proportion of the total runoff volume per year (Olson and Kalischuk 2010). Therefore, the modification of the pivot irrigation system BMP was developed to reduce the volume of runoff caused by irrigation. Most of the irrigation runoff occurred when the pivot system irrigated above the drainage channel. Solenoid switches were installed on the northeast quarter section irrigation pivot system to control the sprinklers on the last two spans of the pivot. These sprinklers were automatically turned off as the pivot system passed through the drainage channel (Figure 5.4).

The pivot irrigation system was modified with the control system and valves in spring 2009. In 2010, programming of the control panel was adjusted so the area not irrigated was better superimposed over the drainage channel. The total area not irrigated remained the same in 2010.

The timing of irrigation and volume of water applied by the northeast pivot was monitored using a McCrometer flowmeter and a Lakewood datalogger. Only one irrigation event occurred on the northeast quarter section in 2010. The pivot operated continuously from July16 to 23, and completed 2.5 circles during this period. The flow was approximately 57 L s^{-1} with the end sprinkler operating, and 51 L s^{-1} without (Figure 5.5). When the pivot passed through the drainage channel, the nozzles of the last two spans of the pivot were turned off reducing the flow to 24 L s^{-1}. Flow was increased for the last three-quarter circle to 30 L s^{-1} when the pivot passed through the grass channel, and to 56 and 61 L s^{-1} when the corner arm was off and on, respectively. Field rain gauges indicated that 27 mm of actual water was applied by each pivot passage.

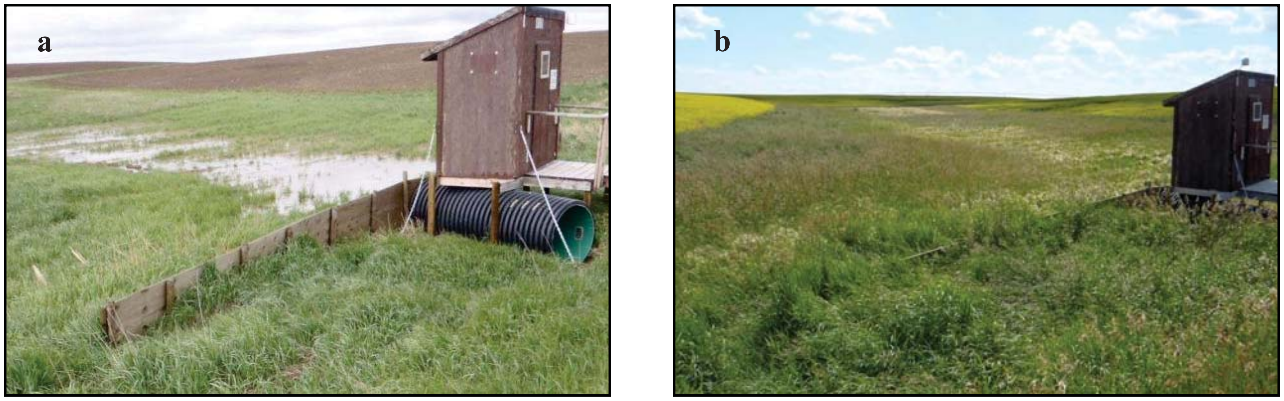

Figure 5.3. The established grass channel and water quality monitoring Station 101 on (a) May 28, 2010 and (b) July 21, 2010.

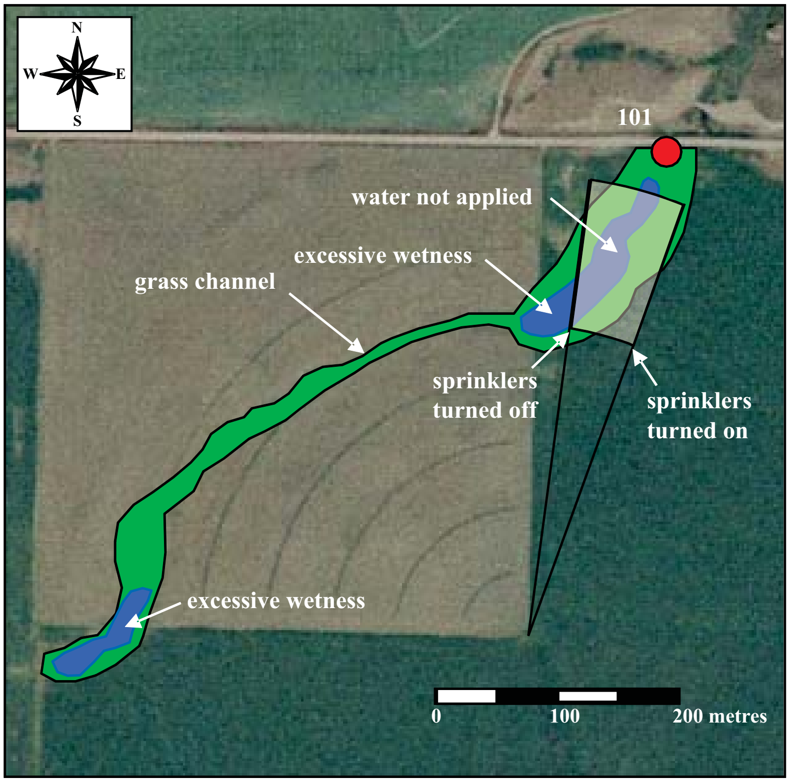

Figure 5.4. Beneficial management practices at the Lower Little Bow River Field site.

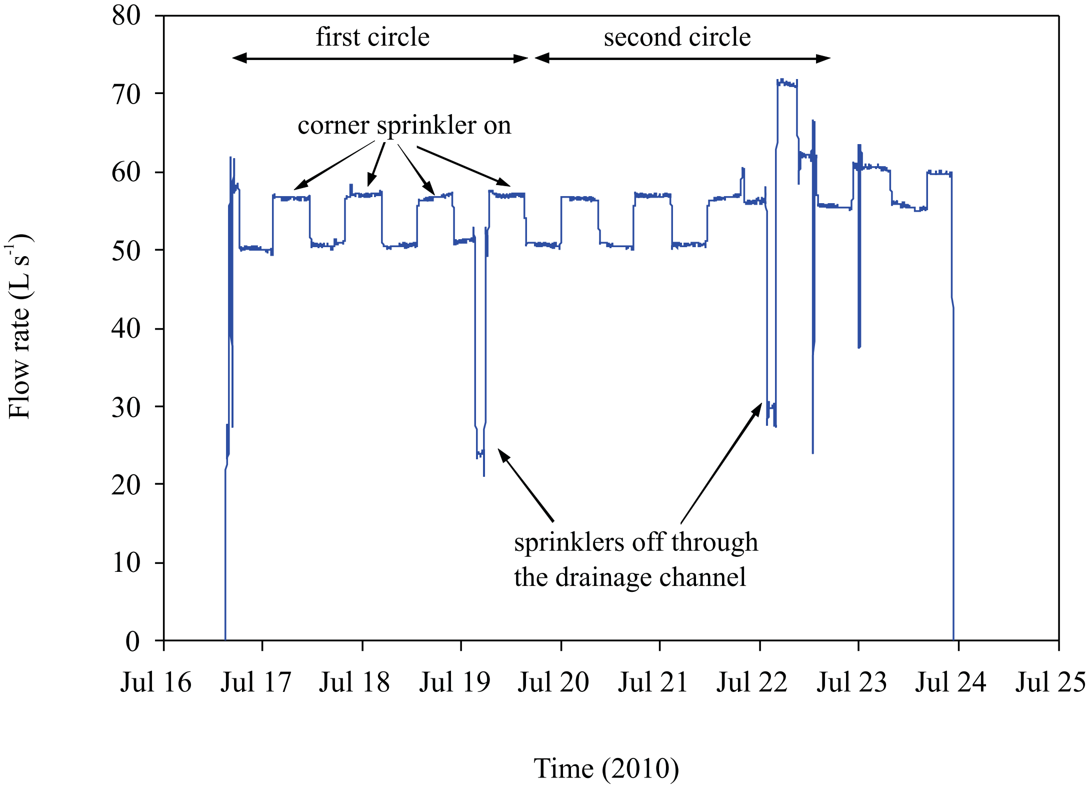

Figure 5.5. Hydrograph of the northeast irrigation pivot system during the irrigation period of 2010.

This BMP worked very well since no runoff was generated by irrigation in 2010. However, because of the wet conditions due to precipitation in 2010, less irrigation occurred compared to the previous years. The total volume of irrigation applied in 2010 was 34,482 m^3 of water, which was 66% less compared to 2008 (Table 5.1). The exact volume applied in 2009 was not available due to problems with the flowmeter and datalogger; however, the pivot was operated for six circles in 2009, and this was used to determine an approximate total volume. Efficacy of the BMP was difficult to assess in 2009 because several rainfall runoff events occurred during the irrigation periods (Olson and Kalischuk 2010).

Comparing the number of irrigation runoff events between the pre-BMP and post-BMP phases does not adequately evaluate the effectiveness of the pivot modifications to reduce runoff. Comparisons should be made relative to the total volume of irrigation water because irrigation demand varies from year to year. Less irrigation results in fewer opportunities for irrigation runoff to occur. For example, in the pre-BMP phase, 2007 was drier and more irrigation was required; whereas, in the post-BMP phase, 2010 had a wet growing season and little irrigation occurred. The total volume of irrigation water applied that was lost as irrigation runoff ranged from 0 to 5.9% from 2007 to 2010 (Table 5.1). On average, the percent loss was less during the post-BMP (2009 and 2010) compared to the pre-BMP phase (2007 and 2008) suggesting the modifications to the pivot system reduced the amount of runoff caused by irrigation. However, in 2009, there was a large percentage of runoff that was caused by a combination of irrigation and rainfall (Refer to Sub-section 5.6.2 for a description of irrigation/rainfall runoff events). When irrigation/rainfall runoff events were added to irrigation only runoff events in 2009, the percent loss became higher, and the average percent of irrigated water loss as runoff was higher in the post-BMP phase compared to the pre-BMP phase.

5.4.3.2 Alberta Irrigation Management Model

The AIMM is a software program designed to help producers schedule irrigation (ARD 2010). The output of the model is a graphic representation of the percent available soil moisture for the crop. The software is also used as a management and record keeping tool for irrigation operators, as well as an irrigation management-training tool. Further details about the AIMM program and output generated by the program is in Olson and Kalischuk (2010).

Table 5.1. The amount of irrigation runoff relative to the amount of irrigated water applied at the Lower Little Bow River Field site from 2007 to 2010.

	2007	2008	2009	2010
Volume irrigated (m^3)[z]	134,735	100,386[y]	116,471	34,482
Volume of irrigation runoff (m^3)[x]	984	5935	4,564	0
Percent loss as runoff (%)	0.7	5.9	3.9	0
Volume of irrigation + irrigation/rainfall runoff (m^3)[x]	984[w]	6982	11,312	0
Percent loss as runoff (%)	0.7	7.0	9.7	0

[z] Volume irrigated on the northeast quarter section only.

[y] Value different than presented in the 2008 Progress Report (Olson and Kalischuk 2009) due to an error in the data processing.

[x] Refer to Sub-section 5.6.2.

Methods. Initial model inputs, including field size, irrigation system type, and soil characteristics, were the same as used in 2009. The field capacity and permanent wilting point values used for the two quarters were determined by soil texture. Other model inputs specific to 2010, such as crop type, seeding date, initial soil moisture, soil texture, and weather data were obtained from the producer or collected in the field and entered at the beginning of the season. Weather data and irrigation input were updated once per week until the end of August.

Weather data were obtained from the Iron Springs, Alberta IMCIN (IMCIN 2010). The precipitation was adjusted as required using the BMP project weather station LWS1 (Figure 5.2). In addition, five rain gauges were installed in the field on May 26 to measure the amount of irrigation water and rainfall during the growing season (Figures 5.6 and 5.7).

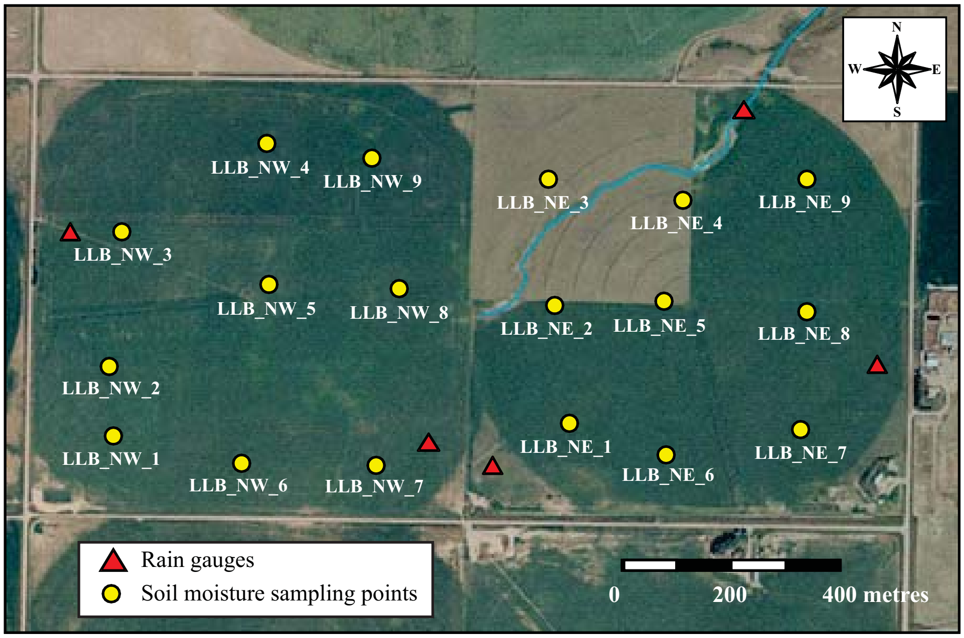

Figure 5.6. Location of soil moisture sample points and rain gauges at the Lower Little Bow River Field site in 2010.

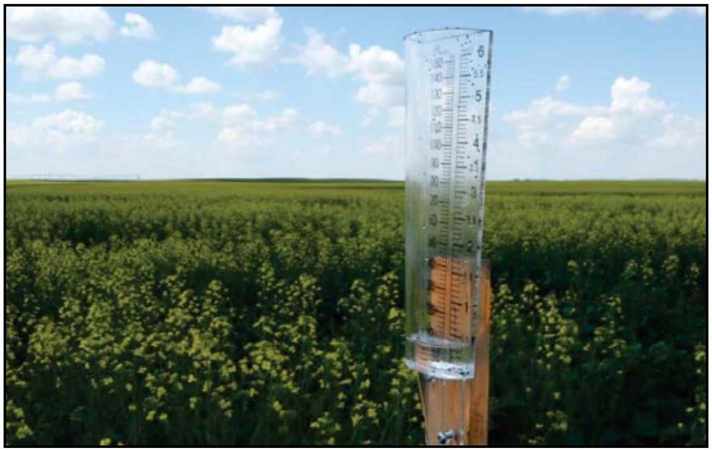

Figure 5.7. A rain gauge used to measure the volume of water applied by irrigation and precipitation at the Lower Little Bow River Field site.

Initial soil moisture samples were collected on May 13, 2010. Sampling procedures used for soil moisture samples were modified compared to 2009 in order to obtain a better representation of high and low areas. Nine soil cores were collected in each of the two quarter sections on May 13 (Figure 5.6). Each soil core was sampled in 25-cm increments to a depth of 1 m using a hydraulic drilling truck and a 5-cm core tube (Figure 5.8). The samples were analyzed for texture and percentage available moisture (Table 5.2). Soil texture was determined by particle size analysis using the Bouyoucos 2-h method with a conversion to a 24-h reading (Karkanis et al. 1991). Soil moisture was determined by oven drying the samples at 105°C for 24 h. From the nine sample locations per quarter section, data from two locations were used for two AIMM scenarios: representative and conservative (Table 5.2). One specific location per scenario allowed field verification of soil moisture if model output needed to be verified or adjusted. The representative location was selected as the most representative of the average soil texture and moisture condition of the entire field. The conservative location was selected to represent areas of the field with the highest need for irrigation, generally areas with lighter textured soils and topographically high areas.

Additional soil moisture samples were collected on July 13, 27, and 29, and August 6 and 10 for the purpose of checking the AIMM output predictions during the growing season. Since the crop was established, these samples were taken by hand using a Dutch auger.

The AIMM model was initiated in the spring using May 13 as the starting date, i.e., the date the initial soil moisture samples were collected. The amounts of rainfall and irrigation water were entered into the model as input data after the initiation date. The model was then run weekly, until the end of August, and recommendations on irrigation was based on the outputs from the model. For the northwest quarter section, the AIMM was run separately for corn and canola since the development and the evapotranspiration are different between these two crops. A soil moisture content of 50% of available water was used as the irrigation threshold.

Figure 5.8. Moisture and texture soil sampling at the Lower Little Bow River Field site on May 13, 2010.

Table 5.2. Texture and moisture results from selected soil samples collected at the Lower Little Bow River Field site on May 13, 2010.

Sample site	Soil layer (cm)	Texture[z]	Reference field capacity[y]	Reference wilting point[y]	Measured available moisture	Percent available moisture (%)
			---------	(mm H_2O 25 cm^{-1})	----------	
LLB_NE_9	0-25	SL-L-SCL	70	28	79.6	100
(representative)	25-50	L	77	33	94.3	100
	50-75	L	72	31	71.5	98
	75-100	SCL-L	68	28	61.2	83
LLB_NE_8	0-25	SL-SCL	69	28	85.2	100
(conservative)	25-50	SL	58	21	65.4	100
	50-75	SL	57	20	84.0	100
	75-100	SL-SCL	61	23	80.0	100
LLB_NW_3	0-25	L-SCL-SL	71	29	96.5	100
(representative)	25-50	SL	64	25	69.5	100
	50-75	L	69	26	87.4	100
	75-100	L	69	27	96.4	100
LLB_NW_9	0-25	SL-SCL	70	29	94.7	100
(conservative)	25-50	SL	63	24	71.0	100
	50-75	SL	59	21	82.2	100
	75-100	SL-SCL	61	23	83.6	100

[z] L= loam, SL= sandy loam, SCL= sandy clay loam.

[y] Reference field capacity and wilting point derived from Saxton et al. (1986).

Results and discussion. Precipitation was well above the 30-yr average in April and May (Subsection 4.2), and this caused very wet conditions at the LLB site (Figure 5.9). The soils in both quarter sections were close to field capacity at the time of sampling on May 13.

The AIMM output showed soil moisture remained above 100% available water content (i.e., field capacity) from the end of May to the end of June (Figure 5.10). As a result, irrigation was not recommended during this period.

Soil samples collected on July 13 showed that the soil moisture content in the northwest quarter section was still above the 100% available moisture (165 mm of available water per metre of soil); whereas, the AIMM modeled value predicted 120 mm of available water per metre of soil, or 70% of available moisture. The model output was adjusted (Figure 5.10a). Since the field was still very wet, the onset of irrigation was delayed until July 22. In the northeast quarter section, the measured soil moisture was 129 mm per metre of soil corresponding to 78% of available moisture. This measured value was slightly higher than the predicted AIMM value of 114 mm.

On the northeast quarter section, irrigation occurred from July 16 to 23, during which 2.5 circles were completed, with 27 mm applied per circle. On the northwest quarter section, irrigation occurred from July 22 to 25, with 16 mm per circle applied twice.

At the end of July, the AIMM output for the canola on northwest quarter section indicated soil moisture was depleted 5 to 6 mm d^{-1} and that irrigation was required during the next week in order to maintain the soil moisture above the recommended 50% of available water. Since the producer believed that the soil moisture was adequate and no irrigation was required, four soil moisture

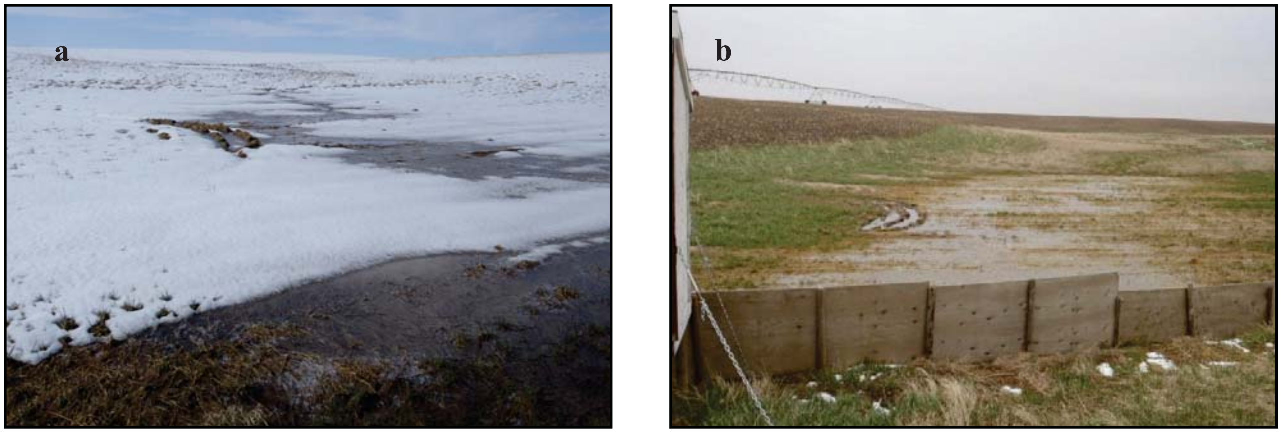

Figure 5.9. Runoff at the Lower Little Bow River Field site on (a) April 16 and (b) May 7, 2010.

samples were taken on July 27 and 29. The results indicated that the soil moisture content was at 100% of available water confirming that the soil moisture was a lot higher than predicted by AIMM. As a result, the model soil moisture was again corrected (Figure 5.10). The rainfall event on August 1 generated some runoff at the edge-of-field water monitoring station, confirming that the soil was very wet. Soil moisture samples collected on August 6 and 10 from the northeast and northwest quarter sections, respectively, confirmed that no further irrigation was required before harvest.

The AIMM program did not successfully predict the soil moisture content at the LLB site in 2010. The inadequate AIMM results may be explained by subsurface water contribution caused by the wet spring conditions in the region (Ted Harms, Alberta Agriculture and Rural Development, Brooks, Alberta; personal communication 2010). The LLB site is at the edge of a coulee leading to the Lower Little Bow River, and is slightly lower than the surrounding area.

Because of this topography, subsurface flow from the high rainfall maintained higher soil moisture content than usual. The AIMM program does not incorporate subsurface flow because this is usually not a factor of importance in irrigated fields in southern Alberta. The irrigation carried out in July was likely not required considering that soil moisture measurements were much higher than predicted by AIMM.

5.4.4 Cost of Beneficial Management Practices

The cost associated with the implementation of the BMPs started in fall 2008 with the increase hauling cost of the manure that would have been applied to the LLB site. The manure was hauled to a greater distance and resulted in a $30,000 increased in transportation cost. In 2009, the manure was hauled to an alternative field at a similar distance as the LLB site from the confined feeding operation, so there was no net increased in manure hauling costs. In 2010, manure that would have been applied to the LLB site was hauled to the same alternative field used in 2008. The seeding of the grass channel and the installation of the irrigation control system on the pivot occurred in spring 2009.

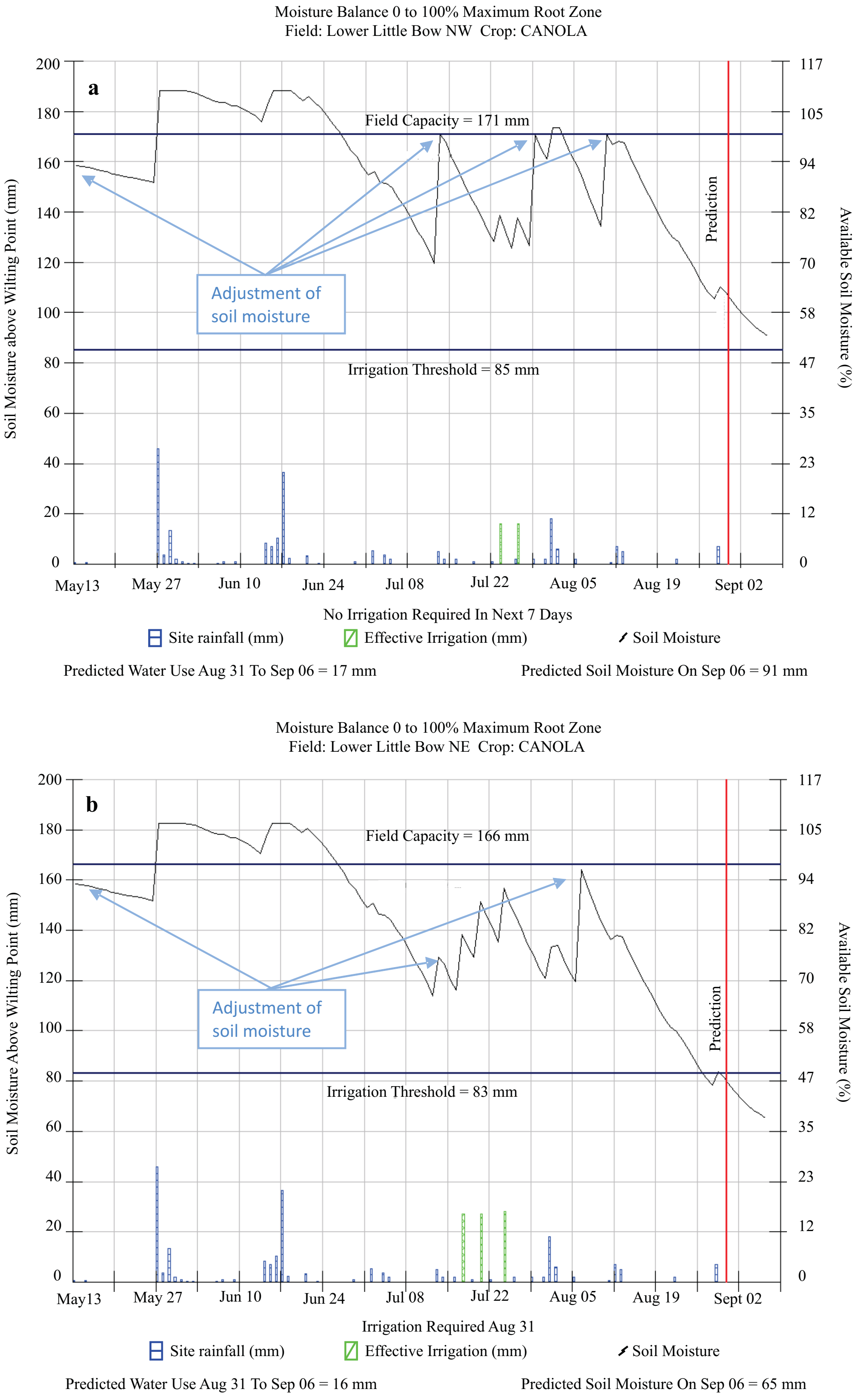

Figure 5.10. Alberta Irrigation Management Model output for the Lower Little Bow River Field northwest (a) and northeast (b) quarter sections in 2010.

2008	Soil testing	$531.00	4 h
	Further distance for manure hauling	$30,000.00	
	Sub-total	**$30,531.00**	**4 h**
2009	Soil testing	$531.00	4 h
	Fertilizer	$0.00	
	Neutron probe access tube (3)	$15.00	
	Rain gauges (3)	$45.00	
	Control panel for pivot	$7,625.00	
	Control panel installation	$720.00	
	Aquamatic shut-off and solenoid values (45)	$3,105.00	
	Installation of values	$2,250.00	
	Grass seed (two, 25-kg bags)	409.53	
	Seeder and tractor rental ($100/h at 4 h)	$400.00	
	BMP labour (grass seeding)	-	8 h
	Further distance for manure hauling	$0.00	
	BMP maintenance and management[z]	-	4 h
	Sub-total	**$15,100.53**	**16 h**
2010	Soil testing	$531.00	4 h
	Fertilizer	$0.00	
	Further distance for manure hauling	$30,000.00	
	BMP maintenance and management[z]	-	8 h
	Sub-total	**$30,531.00**	**12 h**
	Grand total	**$76,162.53**	**32 h**

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

5.5 Soils

5.5.1 Hypothesis

Soil samples (0 to 15 cm) collected bi-annually at the LLB site will be used to test the null hypothesis that the implementation of BMPs (cessation of manure application) will have no effect on soil nutrient concentrations.

5.5.2 Methods

Soil samples collected at the LLB site in 2010 included (1) agronomic soil samples and (2) soil-test samples. The agronomic samples were collected on July 9, 2010 after seeding and on November 2, 2010 after field activities were completed. Soil samples could not be taken in the spring, as in previous years, due to wet field conditions and delayed seeding. Soil sampling points were on a 200-m grid covering the drainage area of the BMP site (Figure 5.1). The 2010 sampling points were located using a GPS unit and were 5 m east of the 2007 positions. There were a total of 23 sampling points. In July, at each sampling point, a Dutch auger was used to collect five, 0- to 15-cm core samples, which were mixed together and sub-sampled. The sub-samples were air dried, ground (< 2 mm), and sent to the laboratory for analysis. Soil samples were analyzed for extractable (nitrate nitrogen) NO_3-N, extractable (ammonium nitrogen) NH_4-N, and STP. The fall sampling was carried out using a truck-mounted hydraulic coring unit in conjunction with the soil-test sampling.

Statistical analyses of the agronomic soil samples comparing the pre- (2007 and 2008) and post-BMP (2009 and 2010) phases were completed using SAS version 9.1 (SAS Institute Inc. 2003). The Univariate procedure was used to test the distribution of the data and the Means procedure was used to generate descriptive statistics. Differences between phases were tested using the Least Squared Means test in the mixed procedure with variance components as the variance structure with the repeated and pdiff options. A significance level of $P < 0.10$ was used in this study.

Due to time constraints, the soil-test samples were collected using the 200- by 200-m agronomic grid rather than transects used in the previous years (Olson and Kalischuk 2010). Because the field has relatively low topographic relief, it was assumed the grid sampling would capture variations within the field as well as the transect sampling and provide representative samples. The soil-test samples were obtained by collecting a single 60-cm core at each grid sampling point in the three increments: 0 to 15 cm, 15 to 30 cm, and 30 to 60 cm. The BMP site consisted of two management units, which were designated northwest and northeast quarter section fields. Samples from all the sampling points within each quarter section were mixed per incremental layer and sub-sampled. There were 14 sampling points in the northwest field and nine sampling points in the northeast field. Samples were air dried, ground (< 2 mm), and sent to the laboratory for analysis. The soil samples were analyzed for extractable NO_3-N, and extractable NH_4-N, and STP.

5.5.3 Results and Discussion

Agronomic concentrations in 2010 were generally similar to previous years, particularly NH_4-N, which varied only by 1 mg kg^{-1} from 2008 to 2010 (Table 5.3). Nitrate-N concentration was lower in the fall compared to the spring in 2010, and this was generally true for the previous 3 yr, except in 2008. There was no consistent trend for STP concentration with time. As in the previous 3 yr, STP concentration in 2010 remained well above the agronomic threshold of 60 mg kg^{-1}.

Comparisons of the pre- and post-BMP phases showed that spring NO_3-N concentration was significantly increased in the post-BMP phase (Table 5.4). Ammonium-N concentrations decreased significantly in the spring and fall in the post-BMP phase compared to the pre-BMP phase. Spring STP concentration was significantly increased in the post-BMP phase; whereas, there was no significant difference between the two BMP phases in the fall. Even though manure application was stopped, the significant increase in the spring NO_3-N and STP concentrations in the post-BMP phase may have been a result of field conditions conducive to net mineralization of residual manure. Preliminary results indicate that the null hypothesis can be rejected for NH_4-N, which was significantly reduced after the cessation of manure. However, the results were inconsistent for NO_3-N and STP between spring and fall regarding a possible BMP effect. This is not unexpected, particularly for STP, due to the probable residual effect of heavy manure application after several years. Additional time is required to determine if STP concentration will decrease with continued cession of manure application.

Soil-test results indicated that NO_3-N concentrations in 2010 varied between the two quarter sections. The northwest quarter section had twice the NO_3-N concentration as the northeast quarter section in the top 0 to 15 cm (Table 5.5). Nitrate N concentrations in the lower two increments were similar for both quarter sections. Ammonia-N and STP were also generally similar in both quarter sections. The AFFIRM software (AAFRD 2005b; Appendix 4) was used to determine fertilizer recommendations. Based on the soil-test results and projected crop, no N or P applications were predicted for 2011.

Table 5.3. Average concentrations for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for the agronomic samples collected from spring 2007 to 2010 at the Lower Little Bow River Field site.

Season and year	NO_3-N	NH_4-N (mg kg^{-1})	STP
Spring 2007	62	5	221
Fall 2007	41	13	263
Spring 2008	13	4	255
Fall 2008	20	4	347
Spring 2009	65	4	248
Fall 2009	22	4	294
Spring 2010	54	3	317
Fall 2010	35	3	273

Table 5.4. Pre-BMP (2007 and 2008) and post-BMP (2009 and 2010) phase comparison of average nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) concentrations in the agronomic soil samples from the Lower Little Bow River Field site.

Phase	NO_3-N	NH_4-N (mg kg^{-1})	STP
Spring pre-BMP	37*b*[z]	5*a*	237*b*
Spring post-BMP	59*a*	4*b*	282*a*
Fall pre-BMP	30	8*a*	306
Fall post-BMP	29	3*b*	284

[z] Average concentrations per parameter and season followed by letters are significantly different at $P < 0.1$.

5.6 Water Flow and Quality

5.6.1 Hypothesis

The underlying assumption is that the over-application of manure nutrients to the soil is contributing excessive nutrients in rainfall, snowmelt, and irrigation runoff at this site. The null hypothesis is that the implementation of BMPs (i.e., cessation of manure application, nutrient management, grass channel, pivot modification, and irrigation scheduling) will have no affect on water quality parameter concentrations in runoff at this site. This site has a single edge-of-field monitoring station and a significant reduction in the concentration in runoff water quality parameters from the pre-BMP phase to the post-BMP phase would suggest a positive effect by the BMPs and a rejection of the null hypothesis.

5.6.2 Methods

The LLB site was equipped with a single edge-of-field monitoring station, which consisted of a circular flume and Isco water sampler (Figures 5.1 and 5.11). Further information on water sampling and sample analysis has been reported in Olson and Kalischuk (2008, 2009, 2010).

Twelve snowmelt, 23 rainfall, and no irrigation runoff samples were collected in 2010. A water sample collected on August 3, 2010 was not included because the sample was not collected and analyzed within the parameter hold times. Daily loads were determined by multiplying the total flow volume by the water quality concentrations in the sample collected that day and 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 water sample.

Table 5.5. Soil-test results for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for samples collected on November 2, 2010.

	NO_3-N		NH_4-N		STP	
Soil layer	NE quarter	NW quarter	NE quarter	NW quarter	NE quarter	NW quarter
(cm)	($mg\ kg^{-1}$)					
0 to 15	37.0	75.5	4.8	7.2	250.0	280.0
15 to 30	25.5	32.5	2.2	2.1	45.2	69.5
30 to 60	26.0	25.0	3.4	2.1	<2.0	14.5

Irrigation and rainfall runoff were sometime difficult to isolate because rainfall occurred when the field was irrigated. Therefore, it was determined that when rainfall events greater than 20 mm fell during irrigation, runoff was considered to be a combined irrigation and rainfall event. Combination events with < 20 mm of rainfall were classified as irrigation runoff.

In 2010, the lab analyzing water samples changed, resulting in the analysis of total nitrogen (TN) instead of total Kjeldahl N and altering the way N fractions were calculated. Quality control information regarding the change in laboratories is summarized in Appendix 1.

Statistical analyses of the water samples were completed using SAS version 9.1 (SAS Institute Inc. 2003). The Univariate procedure was used to test the distribution of the data and the Means procedure was used to generate descriptive statistics. Differences between the pre-BMP and post-BMP phases were tested using the Least Squared Means test in the Mixed procedure with variance components as the variance structure and with the repeated and pdiff options. A significance level of $P < 0.10$ was used in this study.

5.6.3 Results and Discussion

In both pre-BMP years, very little snowmelt runoff occurred in 2007 and there was no snowmelt runoff in 2008 (Table 5.6). Snowmelt generated similar amounts of runoff in both post-BMP years, with 4743 m^3 in 2009 and 5352 m^3 in 2010. The total flow volume of 27,147 m^3 in 2010 was greater than flow volumes measured from 2003 to 2005 (Little et al. 2006) and from

Figure 5.11. Rainfall runoff entering the flume at the edge-of-field monitoring station at the Lower Little Bow River Field site on May 28, 2010.

2007 to 2009 at this site. The larger flow volume in 2010 was due to the above normal precipitation in the spring months (Sub-section 4.2). In 2010, the main runoff events occurred as snowmelt in mid January and the beginning of March and as rainfall runoff from mid April to mid June (Figure 5.12). No irrigation runoff was generated at this site in 2010. This is in contrast to the previous years when irrigation runoff caused 8% to nearly100% of the total flow volume (Table 5.6). This suggests that the pivot modification BMP (i.e., turning off sprinklers as the pivot moved through the drainage channel in the northeast quarter section) was successful at preventing irrigation runoff from this site in 2010.

All of the N fractions, electrical conductivity (EC), and total suspended solids (TSS) concentrations were higher in rainfall runoff than in snowmelt runoff in 2010 (Table 5.7). However, all the P fractions concentrations were higher in snowmelt runoff compared to rainfall runoff in 2010. In 2010, rainfall runoff had lower concentrations of TP, TDP, PP, and TSS but higher concentrations of NO_3-N and NH_3-N compared to the previous 3 yr. This could be attributed to the combined effect of the grass channel and groundwater discharged. The well established grass channel in 2010 could have helped capture soil particles and reduced the concentrations of TSS, PP, and TP. The above average spring precipitation was responsible for large volumes of subsurface water discharge , which could have diluted the TDP concentration but increased the concentration of NO_3-N as groundwater may have been high in NO_3-N. The *E. coli* concentration was low in the rainfall runoff in 2010. Since manure was not recently applied, it would be expected bacteria in manure exposed to sunlight would decrease with time. Also, contributions from subsurface flow may have diluted *E. coli* concentrations.

On average, nutrient concentrations in runoff were higher in 2008 than in 2007, 2009, and 2010 (Table 5.7). Part of this annual variation may be due to the time differences between manure application and runoff monitoring and a dilution effect in 2009 and 2010 (Table 5.6). The runoff contribution area includes portions of the northwest and northeast quarter sections, with the monitoring station located near the northeast corner of the northeast quarter section (Figure 5.1). In fall 2007, manure was applied to both quarter sections. Prior to 2007, manure was applied on high points in the northeast quarter section in fall 2005 and to the entire northwest quarter section in spring 2006. No fresh manure was applied to the lower drainage area leading to the monitoring

Table 5.6. Flow volume measured at the Lower Little Bow River Field site from 2003 to 2010.

Year[z]	Total runoff volume (m^3)	Percent from snowmelt	Percent from rainfall	Percent from irrigation	Percent from irrigation/rainfall[y]
2003	2,968	38	5	57	0
2004	801	32	0	68	0
2005	11,238	0	92	8	0
2007	984	na[x]	na[w]	100	0
2008	11,637	0	40	51	9
2009	19,845	24	18	23	34
2010	27,147	20	80	0	0

[z] 2003 to 2005 data from Little et al. (2006); 2007 to 2010 data from the current study. No data were collected in 2006. The pre-BMP phase was in 2007 and 2008 and the post-BMP phase was in 2009 and 2010.

[y] A combination of irrigation and rainfall when the rainfall portion was greater than 20 mm.

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

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

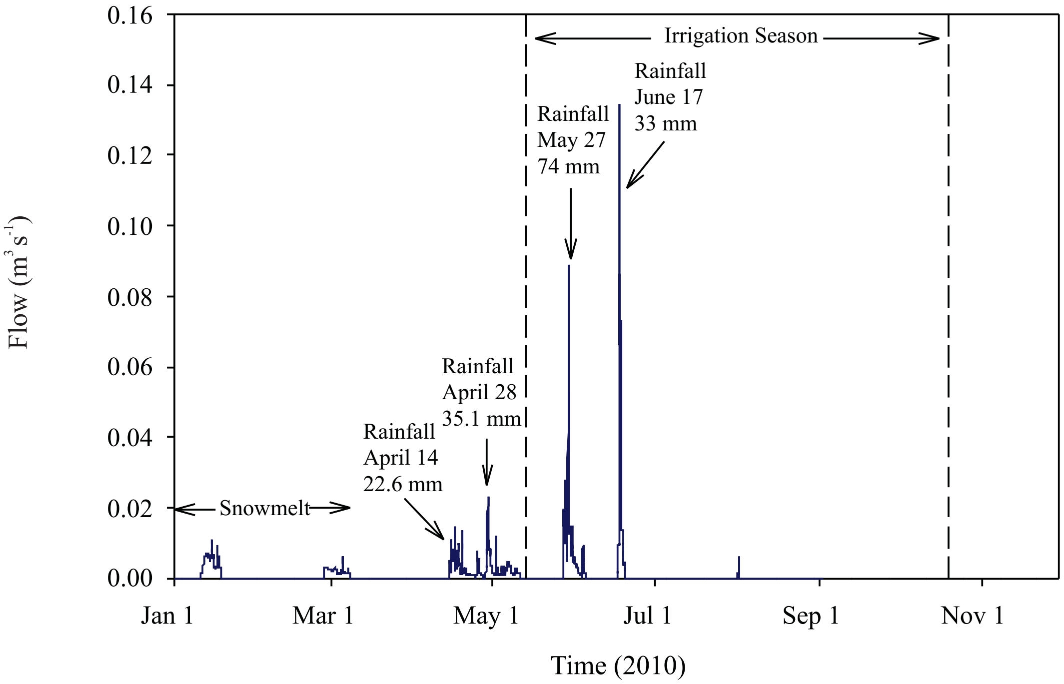

Figure 5.12. Hydrograph for the water monitoring station at the Lower Little Bow River Field site in 2010.

station in fall 2006, and this may explain why the dissolved nutrient concentrations were lower in 2007 compared to 2008. The previous time manure was applied to the entire northeast quarter section was in fall 2004 (Little et al. 2006). In fall 2008, the BMPs were implemented and no manure was applied to either quarter section at this site.

Nitrate-N, ON, and TN concentrations fluctuated during 2010; whereas, NH_3-N generally remained below 1 mg L^{-1}, except at the end of May (Figure 5.13a). Nitrate-N peaked a number of times in 2010 and the largest peaks occurred on June 17 (14.9 mg L^{-1}), May 31 (10.9 mg L^{-1}), and January 15 (8.1 mg L^{-1}). Organic N fluctuated to a lesser degree than NO_3-N and the largest peak occurred on June 4 (9.3 mg L^{-1}). Total N fluctuated in response to changes in NO_3-N concentrations in January, late May, and June and fluctuated in response to ON in April and early to mid-May. The three largest TN peaks occurred on May 31 (19.9 mg L^{-1}), June 17 (17.9 mg L^{-1}), and May 28 (17.5 mg L^{-1}). During the large rainfall runoff in May and June, the NO_3-N concentration increased suggesting a larger groundwater influence in 2010 compared to 2009 at this site.

Total P concentrations were mainly composed of TDP and remained below 3 mg L^{-1}, and PP concentrations remained below 0.5 mg L^{-1} in 2010 (Figure 5.13b). Total suspended solids remained below 50 mg L^{-1} in 2010 (Figure 5.13c). In the previous post-BMP year (2009), TSS concentrations were much more variable, with concentrations that ranged from 3 to 2040 mg L^{-1} (Olson and Kalischuk 2010). In 2009, there was more TSS and PP in irrigation and irrigation/rainfall runoff compared to rainfall runoff (Table 5.7). These high TSS and PP concentrations were likely the result of the disturbance caused by seeding and re-seeding of the grass in the drainage channel.

Table 5.7. Average runoff water quality parameters measured at the Lower Little Bow River Field site from 2007 to 2010.

Event	n	TN[z]	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	*E. coli*	EC
		(mg L^{-1})								(mpn 100 mL^{-1})	(µS cm^{-1})
2007											
Irrigation[y]	4	4.49	4.34	0.06	0.06	1.55	1.36	0.19	53	2248	3420
Rainfall	1	8.53	5.43	2.85	0.17	2.17	2.07	0.10	38	1	6600
All	5	5.30	4.56	0.62	0.09	1.67	1.50	0.17	50	1799	4056
2008											
Irrigation	6	7.48	5.80	1.09	0.27	3.54	3.17	0.37	42	7053	2589
Irrig/rain[x]	2	4.27	4.11	0.04	0.09	2.28	2.07	0.21	23	1290	3110
Rainfall	14	14.47	6.90	6.58	0.63	3.92	3.74	0.18	38	1319	3963
All	22	11.63	6.35	4.49	0.48	3.67	3.43	0.24	38	2881	3511
2009											
Irrigation	5	3.76	2.72	0.74	0.22	2.75	1.96	0.79	523	4014	1552
Irrig/rain[x]	6	4.48	3.09	1.30	0.06	2.83	2.37	0.46	236	988	1793
Rainfall	5	4.67	3.00	1.58	0.03	2.06	1.90	0.16	46	2084	2590
Snowmelt	12	6.90	3.41	1.90	1.34	3.22	3.05	0.17	20	16	1929
All	28	5.42	3.14	1.51	0.63	2.84	2.50	0.34	161	1307	1951
2010											
Rainfall	23	6.52	3.58	2.11	0.69	1.32	1.24	0.08	8	36	3865
Snowmelt	12	5.19	2.71	2.06	0.33	2.14	2.03	0.11	7	68	1771
All	35	6.07	3.28	2.09	0.57	1.60	1.51	0.09	7	47	3147

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

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

[x] Runoff events generated by irrigation and greater than 20 mm of rain.

The *E. coli* concentrations remained below 350 mpn 100 mL^{-1} in 2010 (Figure 5.13d). The highest *E. coli* peaks occurred on May 28 (345 mpn 100 mL^{-1}), January 12 (326 mpn 100 mL^{-1}), and June 17 (291 mpn 100 mL^{-1}). It is uncertain why the *E. coli* concentration was high on January 12, but wildlife is prevalent in the area and the air temperature increased enough to cause runoff in January at the LLB and Battersea Drain Field sites in 2010.

Total loads for all water quality parameters in 2007 were lower than in 2008, 2009, and 2010 because of low flow volumes in 2007 (Table 5.8). The total loads in 2007 were slightly underestimated because the small amount of runoff generated by rainfall was not recorded and some of the runoff from irrigation in late July was not recorded. No snowmelt occurred in 2008, so the loads were due to irrigation, rainfall, and irrigation/rainfall runoff. Loads were greater in 2010 for TN, NO_3-N, and NH_3-N, and this was caused by greater flow volumes compared to the previous 3 yr. This was especially true for NO_3-N, likely because of the greater surface and groundwater interaction suspected in 2010. Organic N, TP, and TDP loads were similar for 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 this was due to the greater concentrations in 2009 (Table 5.7).

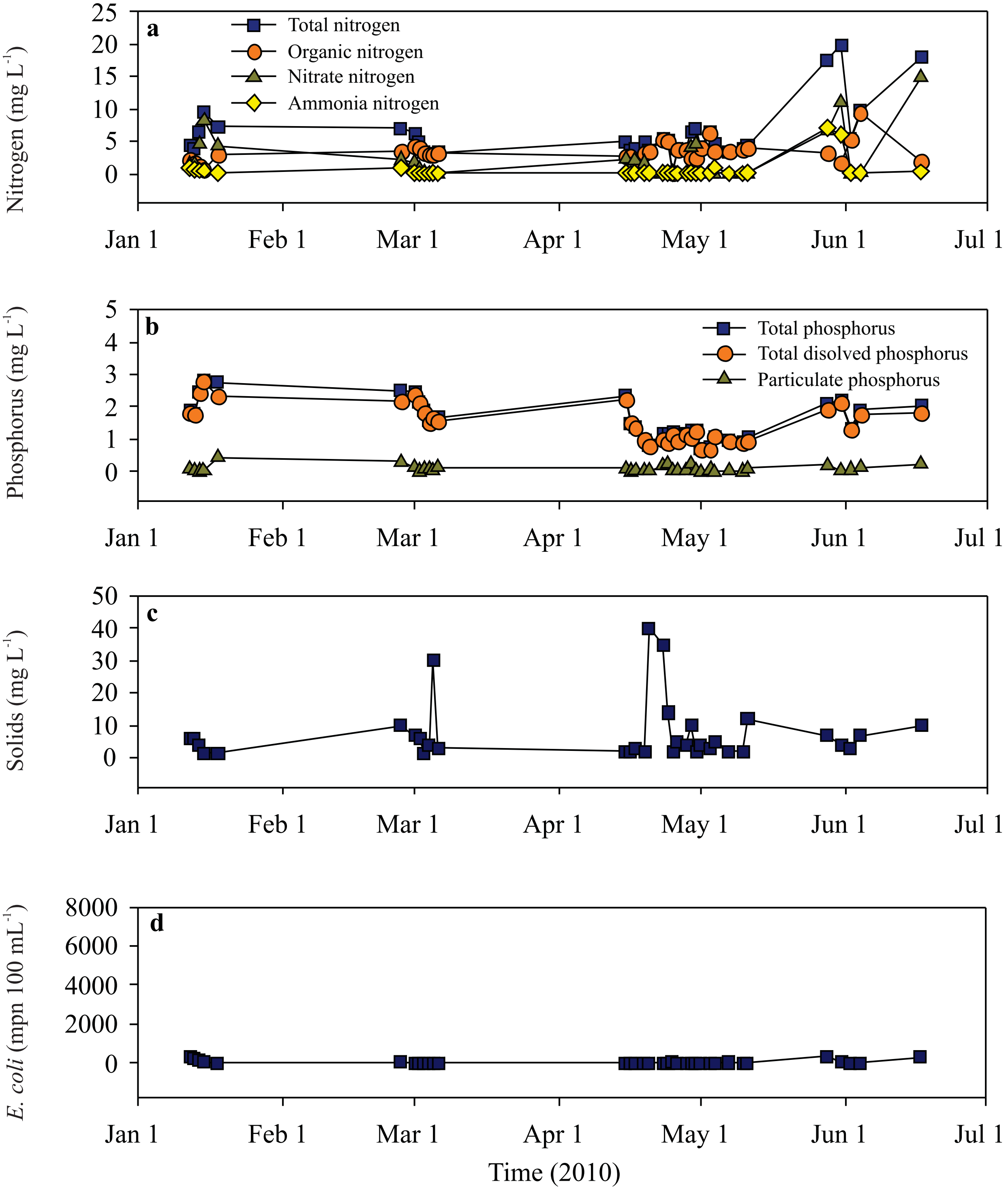

Figure 5.13. Concentration values for (a) total nitrogen, organic nitrogen, nitrate nitrogen, and ammonia nitrogen; (b) total phosphorus, total dissolved phosphorus, and particulate phosphorus; (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) at the Lower Little Bow River Field site in 2010.

Table 5.8. Annual loads of nutrients and total suspended solids in runoff at the Lower Little Bow River Field site from 2007 to 2010.

	TN [z]	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
Year	(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

[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.

5.6.4 Beneficial Management Practices Effects on Water Quality

Concentrations of TN, ON, NO_3-N, TP, TDP, and *E. coli* were significantly less in the post-BMP phase (2009 and 2010) compared to the pre-BMP phase (2007 and 2008) (Table 5.9). *Escherichia coli* concentration was reduced by about two-thirds, and the other parameters were reduced by about one-half. These results suggest that cessation of manure application and the establishment of a grass cover in the drainage channel had a positive effect on runoff water quality at this site.

There were no significant differences between the two BMP phases for NH_3-N, PP, and TSS. As indicated previously, the higher runoff concentrations of PP and TSS in 2009 (i.e., the first post-BMP year) may have been influenced by the disturbance in the drainage channel of seeding and re-seeding the grass in that year. Because of this, the overall post-BMP TSS and PP concentrations were not significantly reduced (Table 5.9). Irrigation runoff was responsible for the highest concentrations of PP in all years except for 2010. The reduction in PP concentrations in 2010 was likely due to a combination of the grass cover and the absence of irrigation runoff (due to the pivot modifications). Also, the loads for these two parameters were reduced in 2010 compared to 2008 and 2009, even though there was more runoff in 2010 (Table 5.8). These load reductions in 2010 also demonstrated the effectiveness of the grass cover and the cessation of irrigation in the drainage channel.

The reduction in N and P concentrations in runoff water from the pre- to the post-BMP phases cannot be readily explained by soil nutrient concentrations measured in the 0- to 15-cm layer. Little et al. (2007) demonstrated a direct linear relationship between STP and runoff TP. Therefore, it could be expected that a decrease in P concentration in runoff water may have been due to reduced nutrient concentrations in soil after the cessation of manure application. However, there was no decrease in extractable soil NO_3-N and STP concentrations in the post-BMP phase compared to the pre-BMP phase (Table 5.4). In fact, soil NO_3-N and STP concentrations in the spring were significantly higher in the post-BMP phase. One possibility for this apparent discrepancy is that the residual STP, without newly applied manure, may have become less exposed to surface runoff, even though STP did not decrease in the top soil layer. Olson et al. (2010) applied manure P in excess of crop requirements and observed a strong STP gradient with depth in the top 15 cm of soil, even though the manure was well incorporated. With the cessation of manure, the likely higher STP concentration near the soil surface (i.e., 1 to 2 cm) may have been reduced by further incorporation from subsequent field activities, such as seeding, without causing a reduction within the 15-cm layer.

Table 5.9. Average water quality parameter concentrations during the pre-BMP and post-BMP phases at the Lower Little Bow River Field site.[z]

Phase[y]	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	*E. coli*	EC
		----	----	----	----	(mg L^{-1})	----	----	----	(mpn 100 mL^{-1})	(µS cm^{-1})
Pre-BMP[x]	27	10.46*a*	6.02*a*	3.77*a*	0.41	3.30*a*	3.07*a*	0.22	40	2680*a*	3612
Post-BMP	39	5.62*b*	3.32*b*	1.74*b*	0.45	1.83*b*	1.59*b*	0.24	114	955*b*	3086

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

[y] The pre-BMP phase includes data from April 7, 2007 until September 10, 2008. The post-BMP phase includes data from June 5, 2009 until June 17, 2010. Snowmelt runoff data (collected from February 11, 2009 to April 30, 2009 and from January 12 to March 6, 2010) were excluded from the BMP phase comparisons because there was no snowmelt runoff collected in the pre-BMP years.

[x] Average BMP phase concentrations per parameter followed by letters are significantly different at $P < 0.10$.

Another possibility is the concentrations of these parameters may have been diluted by the larger volume of runoff and possible contributions from groundwater discharge, which may had lower P concentration. The total runoff volume in the post-BMP phase was 3.7-fold larger than the runoff volume in the pre-BMP phase (Table 5.6).

5.7 Summary and Future Work

The second year of post-BMP monitoring was carried out at the LLB site in 2010. Canola was grown on the northeast quarter section and the south half of the northwest quarter section. Corn was grown on the north half of the quarter section. Due to poor growth, a portion of the canola field was reseeded to barley. The BMPs were implemented in 2008 and 2009 and maintained in 2010. The BMPs included (1) development of a nutrient management plan (cessation of manure application and managing for soil N), (2) establishment of a grass channel, and (3) improvement of irrigation management and runoff control (turn off nozzles in the critical source area and using AIMM).

Total annual precipitation received in 2010 was 451 mm including 286.6 mm during the growing season. This amount was above the 30-yr average and the previous years of the project (2007 to 2009). Monthly average daily temperatures were less than the 30-yr average between April and September.

The period of irrigation was less than 2 wk in 2010 because of the above average precipitation in the spring and summer. The AIMM program did not successfully predict the evolution of soil moisture in 2010. The inadequate AIMM results may have been caused by subsurface water contribution as a result of the wet spring conditions in the region.

The cost associated with the implementation of the BMP in 2010 was estimated at $30,000, which was for hauling manure a greater distance from the feedlot. The grand total BMP cost to date is $76,163, with 32 h of labour.

Soil NH_4-N concentrations decreased significantly in the spring and fall in the post-BMP phase compared to the pre-BMP phase. Even though manure application was stopped, spring soil NO_3-N and STP concentrations were significantly greater in the post-BMP phase compared to the pre-BMP phase.

The total runoff flow volume in 2010 was 1.4 to 28-fold larger than in the previous 3 yr of the study. The larger volume in 2010 was due to the above average precipitation in the spring months.

There were significant reductions in TN, ON, NO_3-N, TP, TDP, and *E. coli* concentrations in the post-BMP phase compared to the pre-BMP phase. These results suggest that cessation of manure application and the establishment of a grass cover in the drainage channel had a positive effect on runoff water quality at this site. No runoff was generated by irrigation in 2010, indicating a positive effect of the pivot modification BMP. Total load reductions in PP and TSS in 2010 also demonstrated the effectiveness of the grass cover and the cessation of irrigation in the lower part of the drainage channel.

In 2011, the third year of the post-BMP phase will be carried out at the LLB site. Future work at the LLB site will include continued monitoring of soil and runoff water quality and management of irrigation to minimize irrigation runoff. Manure will not be applied before the fall 2011 and a nutrient management plan will be used to determine crop N requirements.