

SECTION 4

BATTERSEA DRAIN FIELD SITE

4.1 Introduction

The Battersea Drain Field (BDF) site is a quarter section field bisected by the Battersea Drain and is located about 18 km northeast of Lethbridge (NE9-11-20-W4). The site is equipped with a centre pivot irrigation system with corner arm (Figure 4.1). Cattle manure is typically applied on the field from the producer's cattle feedlot located nearby. Further details of the site are described in Olson and Kalischuk (2008, 2009, 2010).

The main concern for this site is the elevated soil nutrient concentrations from manure application, particularly soil-test phosphorus (STP), and the high concentrations of phosphorus (P), nitrogen (N), sediment, and bacteria in edge-of-field runoff. Soil and water quality were monitored for 2 yr prior to the implementation of beneficial management practices (BMPs) as the pre-BMP phase. The implemented BMPs included (1) development of a nutrient management plan and (2) modifications to the irrigation pivot system and irrigation scheduling to control runoff in the critical source areas. The BMPs were implemented in fall 2008 and spring 2009.

4.2 Weather

4.2.1 Methods

The nearest weather station to the BDF site used by Environment Canada is near Iron Springs, Alberta (Irrigation Management Climate Information Network (IMCIN); latitude 49° 54' 2", longitude 112° 44' 24", elevation 893 m). 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 (AARD 2011b). The 30-yr average (1971 to 2000) values were obtained from the Lethbridge Canada Department of Agriculture (CDA) weather station (latitude 49°



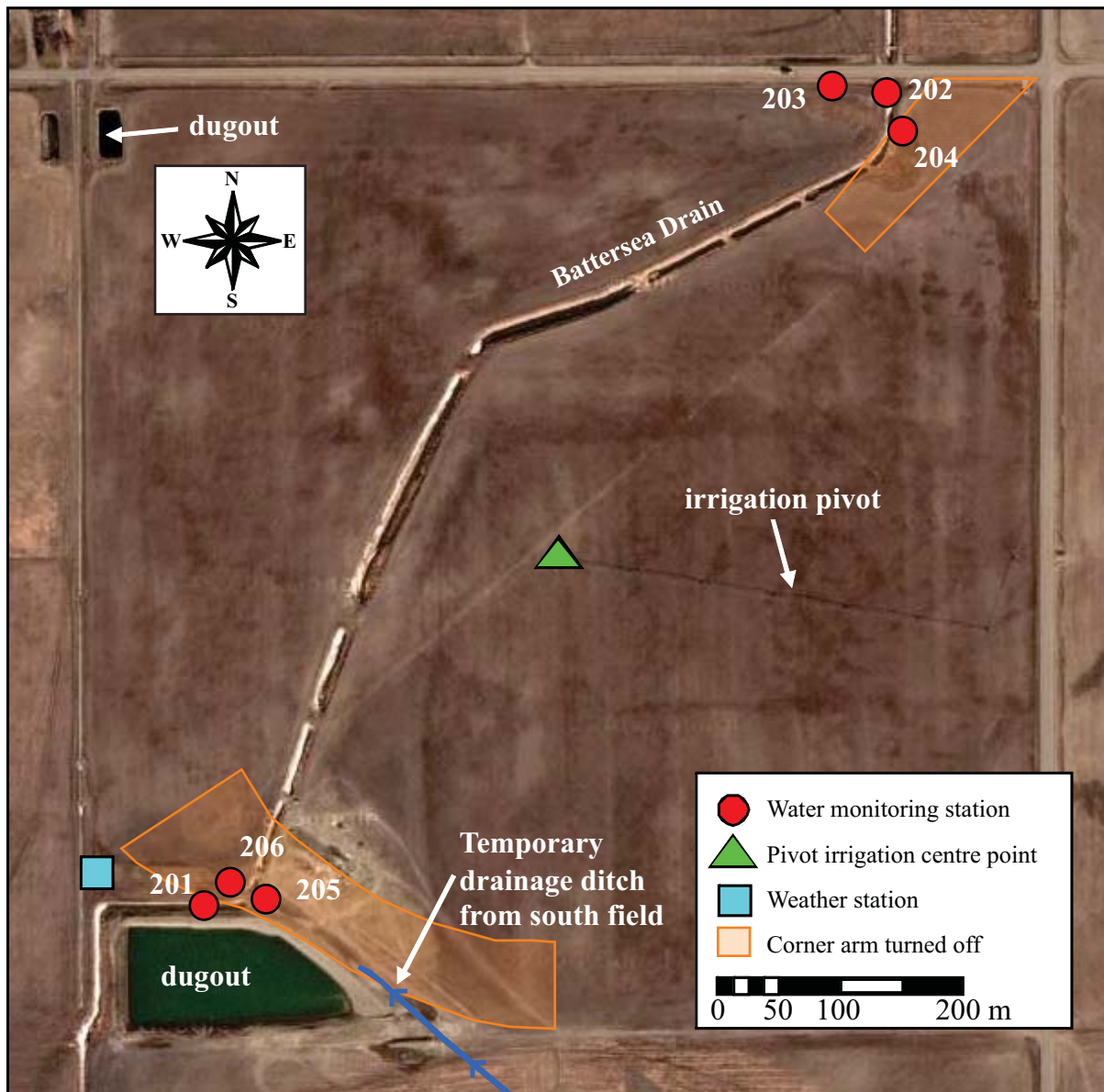


Figure 4.1. Battersea Drain Field site showing the Battersea Drain, the upstream (Station 201), downstream (Station 202), and four edge-of-field (Station 203, 204, 205, and 206) water monitoring stations as well as the area where irrigation is controlled by the pivot irrigation system modification in 2010.

41' 42", longitude 112° 46' 3", elevation 910 m) because of the lack of historical data from the Iron Springs station (Environment Canada 2011).

A weather station was installed at the BDF site (BWS1) in June 2008 for the modelling needs of the project (Figure 4.2). The station was equipped to measure relative humidity, temperature, and precipitation. A snow adapter was added to the rain gauge and used from early November to early June in order to measure snowfall. Further information about the weather station can be found in Olson and Kalischuk (2009, 2010).



Figure 4.2. The weather station at the Battersea Drain Field site.

4.2.2 Results and Discussion

The monthly average daily temperatures for 2010 at the BDF site were similar to the 30-yr average. Monthly average daily temperatures in 2010 were warmer in February, March, April, and October when compared to 2007; whereas, all remaining months were cooler in 2010. Compared to 2008, temperatures were generally warmer in 2010 except for May, July, August, September, and November. Compared to 2009, temperatures were warmer in 2010 for most months, except for May, August, September, and November (Figure 4.3a).

Total annual precipitation received in 2010 was 451 mm, which was above the 30-yr average of 365 mm. Total precipitation in 2010 was also above the amounts recorded in 2007 (255 mm), 2008 (409 mm), and 2009 (387 mm). In 2010, April through June, August, and November received above average precipitation, while the other months received precipitation below the average (Figure 4.3b). Precipitation during the 2010 growing season (April to September) was 386.6 mm, which was more than the 30-yr average of 256.7 mm for the same period. Total precipitation received between April and September of 2010 was also greater than what was received during this period in 2007, 2008, and 2009.

The precipitation data collected in 2010 at BWS1 was similar to the Iron Springs data for most months, except for August, November, and December (Figure 4.3c). Approximately 25% more precipitation was recorded at the BWS1 station in August compared to the Iron Springs station. The BWS1 station recorded 35% of the precipitation recorded at the Iron Springs station in November and 7% of the precipitation recorded at the Iron Springs station in December.

The majority of the precipitation in 2010 fell from April to June, with 95.0 mm in April, 101.4 mm in May, and 72.2 mm in June. The precipitation received during these 3 mo was 59.5% of the total annual precipitation. Major rainfall events in 2010 occurred on April 14 (22.6 mm), April 28 (35.1 mm), May 27 (64 mm), and June 17 (33 mm) (Figure 4.4).

4.3 Routine Management Activities in 2010

The BDF site was seeded on April 23, 2010. The most recent crops grown of the 4-yr rotation was barley silage in 2006, potato in 2007, corn silage in 2008, canola in 2009, and barley silage in 2010. As recommended by the irrigation management plan BMP, no manure or commercial fertilizer was applied in 2010. The Alberta Irrigation Management Model (AIMM) software (ARD 2010) was used to determine the timing of irrigation. Irrigation started on July 12 and continued until July 25. Three circles of 16 mm were applied followed by two circles of 25 mm for a total of 98 mm. The barley was harvested as silage on August 6 and yielded 25.9 Mg ha⁻¹ (wet weight).

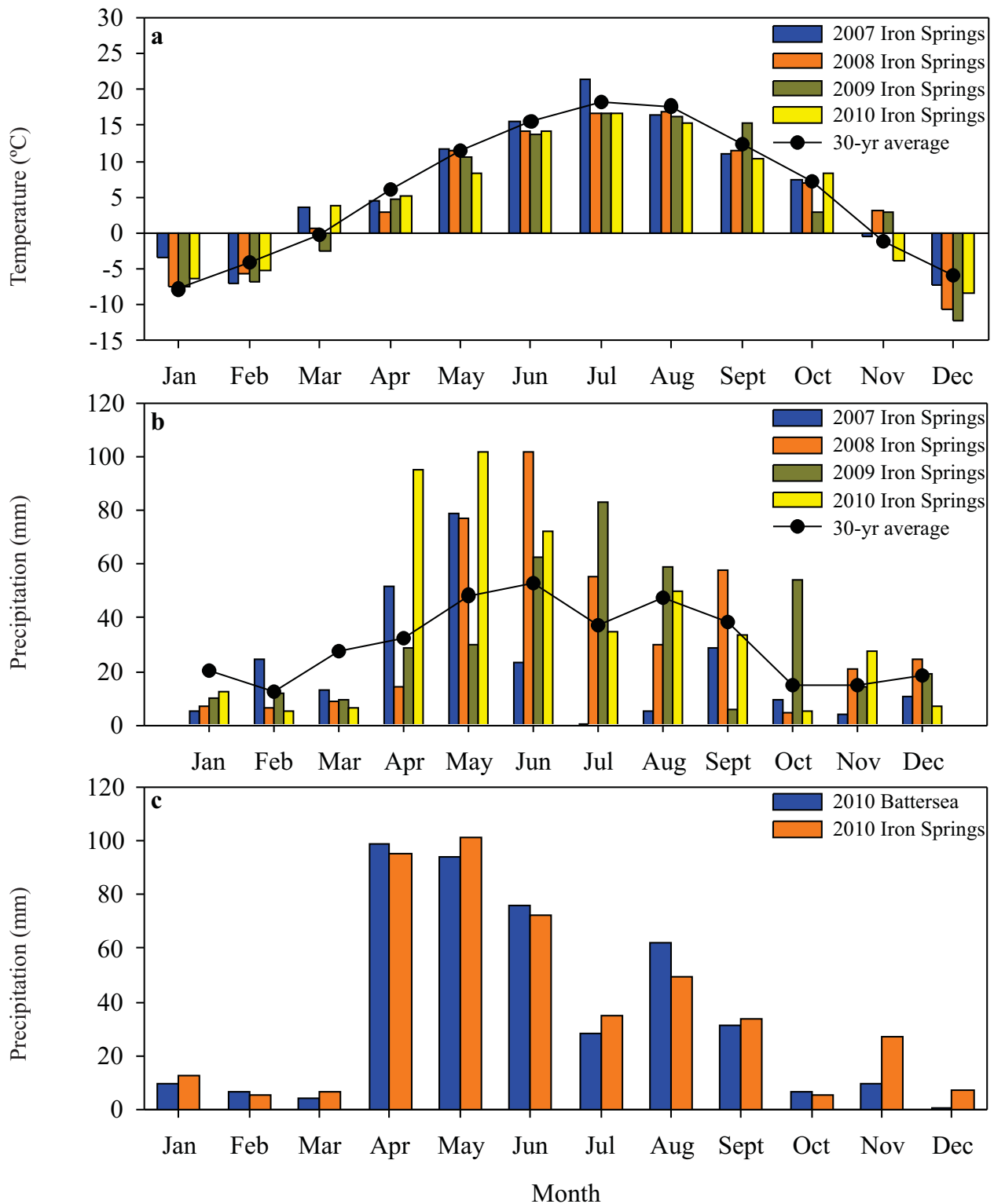


Figure 4.3. Comparison of 30-yr averages (1997 to 2000) with (a) monthly average daily temperature, (b) total monthly precipitation, and (c) total monthly precipitation from the Battersea Drain Field weather and Iron Springs stations. The 30-yr averages (Lethbridge CDA) and Iron Springs data are from Environment Canada (2011).

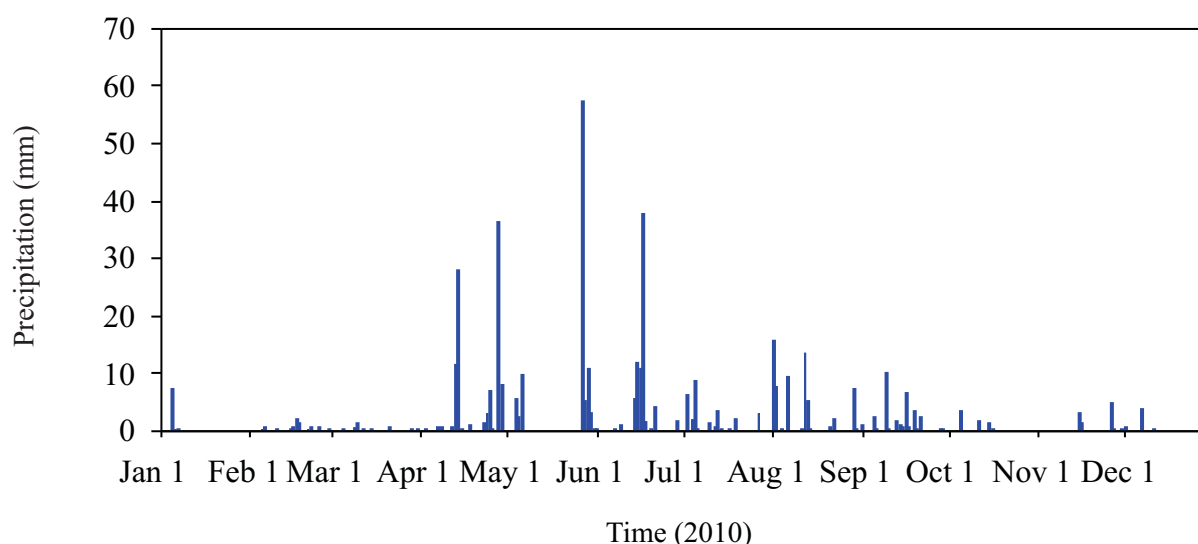


Figure 4.4. Total daily precipitation at the Iron Springs weather station. Data from Environment Canada (2011).

4.4 Beneficial Management Practices Activities in 2010

Data collected during the pre-BMP phase (2007 to 2008) showed that runoff water collected at the edge-of-field monitoring stations contained high concentrations of nutrients and bacteria. The water quality in the Battersea Drain is generally of better quality during the growing season because of the dilution from the water provided by the irrigation district. Outside of this period, water in the drain contains high concentration of N in particular. Surface runoff occurred during snowmelt, rainfall, and irrigation events, although the majority of runoff events during the pre-BMP years were from irrigation. Concentration of STP greatly exceeded the agronomic threshold of 60 mg kg^{-1} , above which crops will generally not respond to added P (Howard 2006).

The post-BMP monitoring phase at the BDF site began in spring 2009. The implemented BMPs included (1) development of a nutrient management plan and (2) modifications to the irrigation pivot system and irrigation scheduling to control runoff in the critical source areas.

4.4.1 Nutrient Management Plan

The nutrient management plan composed of two BMPs: (1) the cessation of manure application because of high STP and (2) fertilizer N recommendations. In the pre-BMP period, the average fall STP concentration in the 0- to 15-cm soil layer was 412 mg kg^{-1} (Olson and Kalischuk 2010), which is well above the agronomic threshold of 60 mg kg^{-1} (Howard 2006) and crops would not benefit from the addition of P. The last manure application was in the fall 2007. In the fall of 2010, manure that could have been applied to the site was transported about 9 km to the east and stockpiled on two quarter sections, on which the manure will be spread in spring 2011. This alternate site is adjacent to the alternate site used in fall 2009.

The nutrient management plan was also used to develop N fertilizer recommendation for 2010. On October 13, 2009, soil samples were collected in three incremental depths: 0- to 15-cm, 15- to 30-cm, and 30- to 60-cm (Olson and Kalischuk 2010). The Alberta Farm Fertilizer Information and Recommendation Manager (AFFIRM) program was used to determine nutrient recommendations (AAFRD 2005b; Appendix 4). The AFFIRM results recommended no nutrient application for the 2010 crop year with barley silage as the crop.

4.4.2 Irrigation Management

The irrigation management BMP was composed of two main aspects: (1) pivot irrigation system modifications and (2) using the AIMM program to schedule irrigation.

4.4.2.1 Pivot Irrigation System Modifications

Methods. During the pre-BMP period, irrigation was often the largest proportion of the total runoff volume per year. The pivot irrigation system was modified to reduce the volume of runoff caused by irrigation in the critical source areas in the field, which were in the proximity of the edge-of-field water quality monitoring Stations 204, 205, and 206 (Figure 4.1). Solenoid valves were installed to switch the corner arm sprinklers on and off as the pivot passed through the critical source areas (Figures 4.1 and 4.5).

Observations in 2009 showed that even with these modifications to the irrigation pivot system, the low area draining to Station 205 continued to have excess water on the surface (Olson and Kalischuk 2010; Figure 4.6). In spring 2010, the irrigation pivot system was further modified so that half of the nozzles on the last span before the corner arm could be turned off to reduce the amount of water applied on the low area draining to Station 205 (Figure 4.7).



Figure 4.5. Pivot irrigation system at the Battersea Drain Field site showing the corner arm sprinklers turned off as the pivot passed by Station 204 on July 16, 2010.



Figure 4.6. The lower area draining to Station 205 at the Battersea Drain Field site showing excess moisture in July 2009.

In 2009, irrigation runoff was also observed at Station 204 after the irrigation system was modified (Olson and Kalischuk 2010). However, unlike Station 205, the same number of sprinklers was turned off at Station 204 in 2010 as in 2009. However, minor adjustments were made to the control system in 2010 so the nozzles were turned off on the corner arm for a longer period near Station 204 (Figure 4.8).

The timing of irrigation and volume of water applied with the pivot irrigation system was monitored using a McCrometer flowmeter and a Lakewood datalogger. Only one irrigation event occurred in 2010. The pivot ran continuously from July 12 to 25 and completed five circles during this period (Figure 4.9).

Because of a malfunction of the flowmeter datalogger, it was not possible to accurately measure the irrigation flow. However, it was possible to confirm the reduction of irrigation flow when the nozzles on the corner arm were turned off as the pivot passed through the two areas most susceptible to irrigation runoff (Figure 4.9), i.e., at Stations 204 and 205. Rotational speed of the pivot was decreased for the last two circles in order to increase the volume of water applied per circle. Field rain gauges indicated that 16 mm per circle were applied during the first three circles and 25 mm per circle were applied during the last two circles (Figure 4.10).

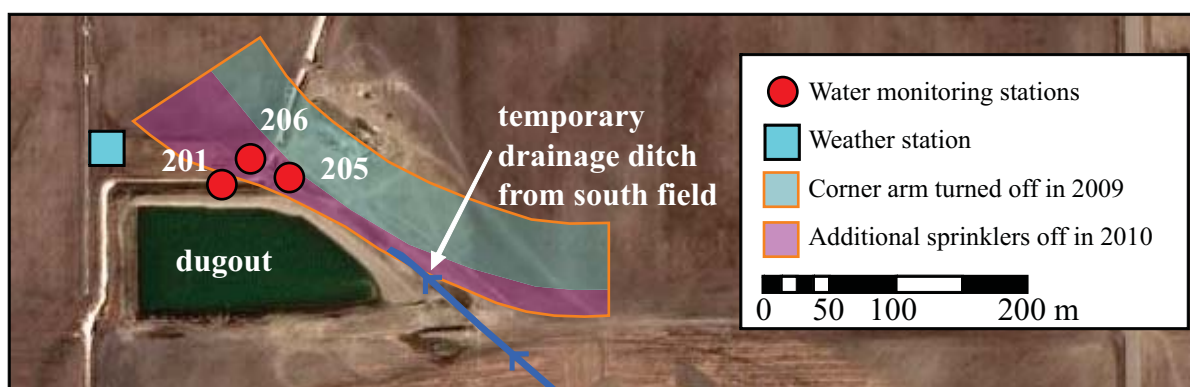


Figure 4.7. Additional area (in green) where sprinklers were turned off in 2010 as part of the pivot irrigation system modification at the Battersea Drain Field site.



Figure 4.8. The irrigation pivot corner arm nozzles are turned on after passing through the critical source area (from right to left in the image) near Station 204 at the Battersea Drain Field site on July 16, 2010.

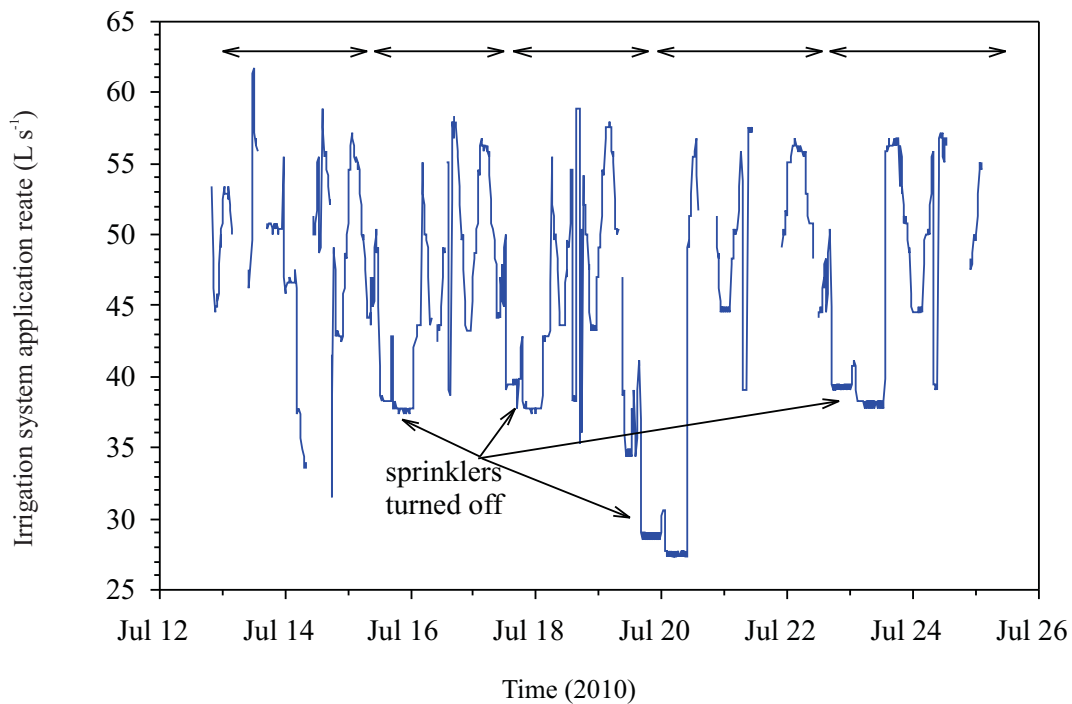


Figure 4.9. Hydrograph of the irrigation pivot system at the Battersea Drain Field site during the irrigation period of 2010. The arrows indicate a full pivot circle around the field and reduced flow over the critical source area near Station 205.



Figure 4.10. Manual rain gauge used to measure the amount of irrigation and rain received on the barley crop at the Battersea Drain Field site in 2010.

Results and discussion. Of the four edge-of-field water quality monitoring stations, Stations 205 and 206 were used to evaluate the effectiveness of the BMP in 2010. The pivot control system was not programmed to turn off the sprinklers near Station 203 because very little irrigation runoff occurred at this station (Olson and Kalischuk 2010). The effectiveness of the BMP at Station 204 could not be evaluated in 2010 because the water level in the Battersea Drain backed up into the flume at Station 204 during the irrigation period, making it impossible to measure runoff at this edge-of-field station (Figure 4.11). The elevated water level in the drain in 2010 was caused by wet spring conditions, which reduced the need for irrigation thus creating a surplus of water in the irrigation district canal system.

The BMP was effective at Station 206 in the post-BMP phase. Irrigation runoff occurred 40 times during the pre-BMP period (2007 and 2008); whereas, only two irrigation runoff events occurred in the post-BMP period (2009 and 2010). In contrast, the additional modification made to the pivot system in spring 2010 did not eliminate irrigation runoff at Station 205. Irrigation runoff was observed each of the five times the pivot passed through the critical source area at Station 205 during the irrigation period from July 13 to 25, 2010 (Figure 4.12). Two additional runoff events occurred during this period on July 21 and 23, and these two runoff events were not influenced by irrigation or rainfall and were attributed to a temporary ditch draining water from the quarter section immediately to the south (Figures 4.7 and 4.13b). This ditch water kept the area by Station 205 very wet and probably contributed to runoff when the pivot system passed over the area.



Figure 4.11. Station 204 in May 2010 showing (a) water from the Battersea Drain entering the outlet of the flume and (b) the flume inlet with standing water from the drain.

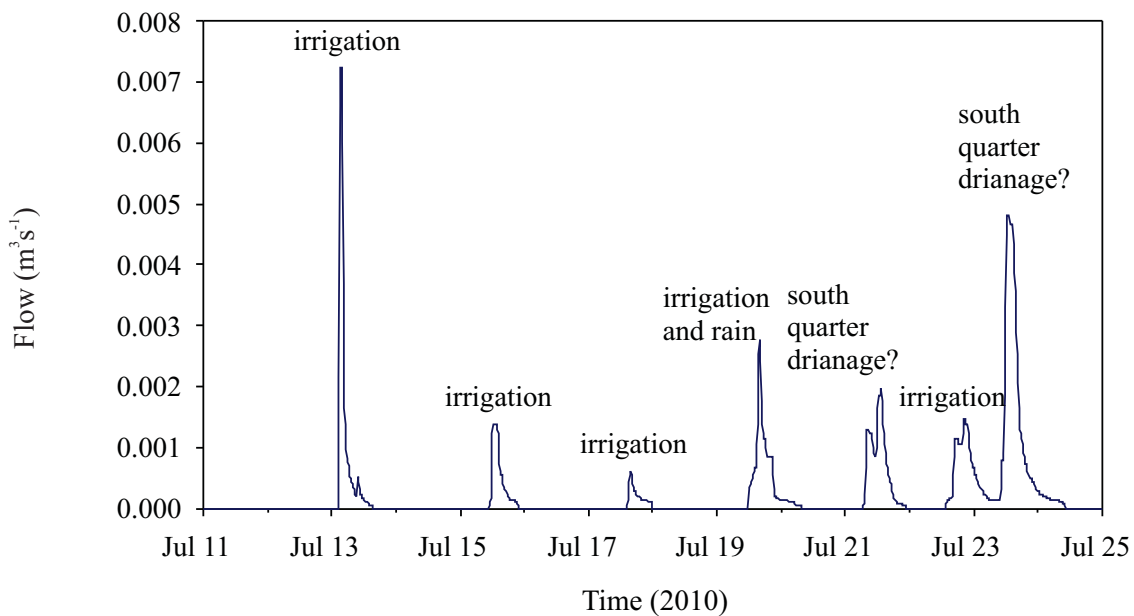


Figure 4.12. Hydrograph of runoff flow at Station 205 in 2010.

The main reason why irrigation runoff continued at Station 205 may be explained by the presence of stagnant water pooled in front of the edge-of-field station. As a result, the addition of any water to the area caused the pooled water to generate runoff at Station 205. This area tended to stay wet longer because of the lower elevation relative to the surrounding area and poor infiltration. Excess water was also observed following spring snowmelt and rainfall. The water level in the Battersea Drain rose higher than normal during the wet spring and the flow backed-up through the flume at Station 205 (Figure 4.14) and flooded the low area upstream from Station 205 (Figure 4.13a).

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 less irrigation occurred. The

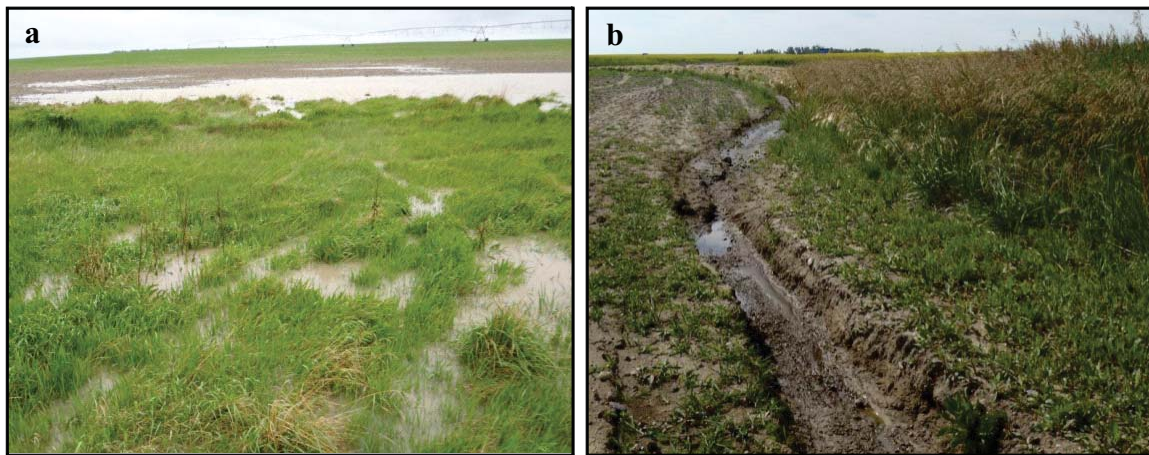


Figure 4.13. Flooded area in the (a) grass buffer and low area of the southeast corner of the Battersea Drain Field site that drained to Station 205 in spring 2010 and (b) the temporary ditch that drained the quarter section immediately south of the Battersea Drain Field site to Station 205.



Figure 4.14. Backed-up water from the Battersea Drain at Station 205 on May 28, 2010.

total volume of irrigation water applied that was lost as irrigation runoff ranged from 0.2 to 2.8% from 2007 to 2010 (Table 4.1). 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. In 2009, there was a large percentage of runoff that was caused by a combination of irrigation and rainfall (Refer to Sub-section 4.6.2 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 was higher, and the average percent of irrigated water loss as runoff was similar between the pre-BMP and post-BMP phases.

4.4.2.2 Alberta Irrigation Management Model

The AIMM program is a tool designed to help producers schedule irrigation for a variety of crops (ARD 2010). The software can also serve as a management and record keeping tool for irrigation operations as well as an irrigation management training tool.

Methods. Initial model inputs including crop type, seeding date, initial soil moisture, and weather data were obtained from the producer or collected in the field and entered into AIMM at the beginning of the season. Other model input data, including field size and irrigation system characteristics, were the same as used in 2009 (Olson and Kalischuk 2010).

The weather data were collected from the Irrigation Management Climate Information Network for Iron Springs, Alberta (IMCIN 2010). The precipitation data were adjusted as required using the BMP project weather station BWS1 (Sub-section 4.2), as well as additional manual rain gauges within the field at the BDF site (Figure 4.15).

Initial soil moisture samples were collected on April 27, 2010. Nine soil cores were sampled (Figure 4.15), and each 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 4.16). The samples were analyzed for texture and percentage available moisture. 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. The average available moisture content and particular size distribution for each 25-cm soil layer was calculated and used for the AIMM input data (Table 4.2). Soil bulk density values were used to convert gravimetric moisture values to volumetric moisture values. Additional soil moisture samples were collected on July 13 to confirm or adjust the AIMM soil moisture value during the growing season. Since the crop was established, these samples were taken by hand using a Dutch auger.

Table 4.1. The amount of irrigation runoff relative to the amount of irrigated water applied at the Battersea Drain Field site from 2007 to 2010.

	2007	2008	2009	2010
Volume irrigated (m ³)	280,257	216,469	87,190	46,823
Volume of irrigation runoff (m ³) ^z	2,236	6,087	702	85
Percent loss as runoff (%)	0.8	2.8	0.8	0.2
Volume of irrigation + irrigation/rainfall runoff (m ³) ^z	2,236	6,114	3,247	85
Percent loss as runoff (%)	0.8	2.8	3.7	0.2

^z Refer to Sub-section 4.6.2.

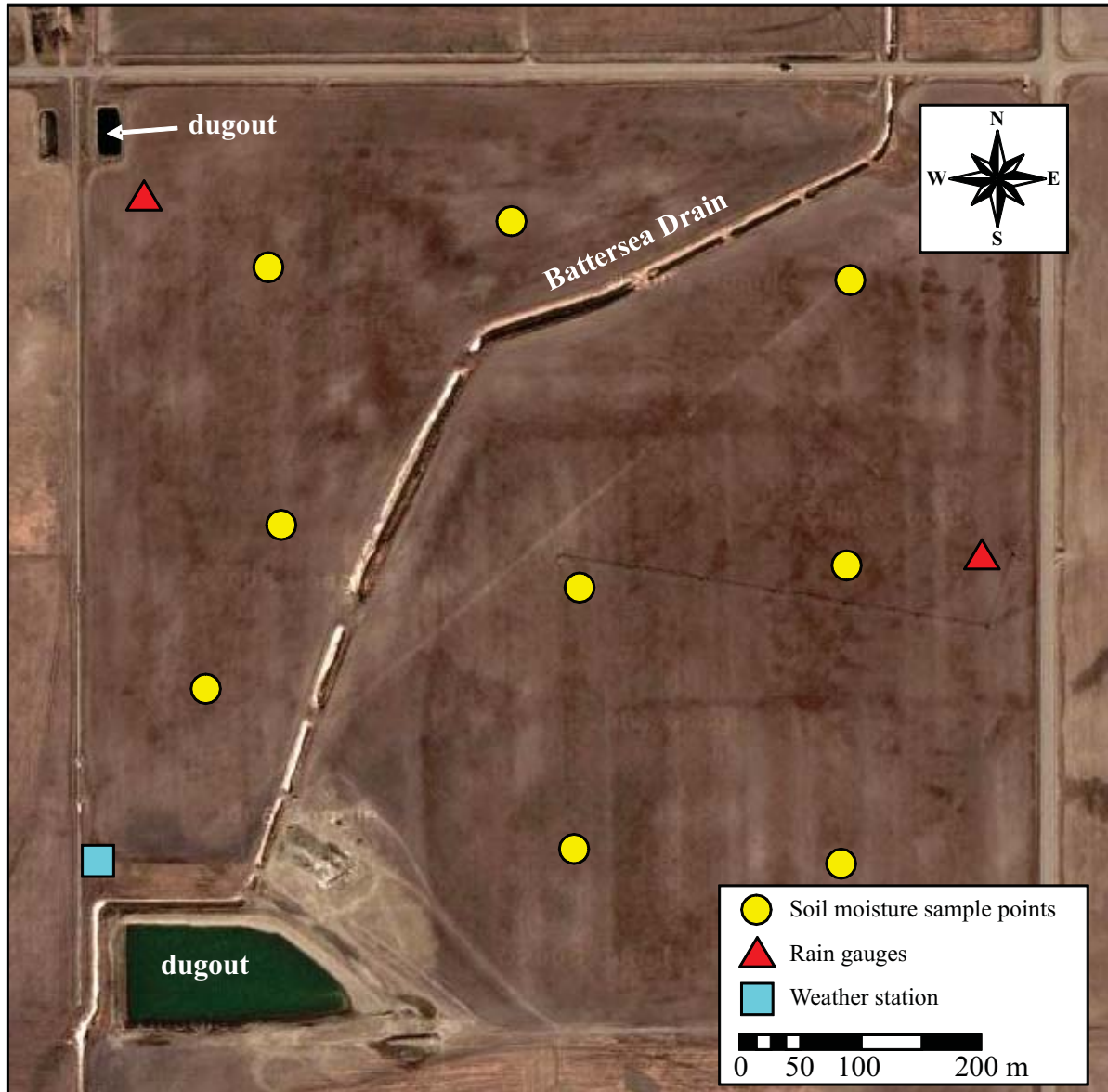


Figure 4.15. Soil moisture sample points and manual rain gauges at the Battersea Drain Field site in 2010.

The AIMM simulation was initiated on April 27, 2010. All water applied to the field from rainfall and irrigation was entered into the model simulation after this date for the duration of the growing season. Two manual rain gauges were installed within the irrigated field on May 26, 2010 (Figures 4.10 and 4.15). The manual rain gauges were used to record rainfall and irrigation water in addition to the precipitation data recorded by the BDF weather station.



Figure 4.16. Moisture and texture soil sampling on April 27, 2010 at the Battersea Drain Field site.

Table 4.2. Average particle size distribution and moisture values from soil samples collected on April 27, 2010 at the Battersea Drain Field site.

Soil layer (cm)	Sand (%)	Clay (%)	Silt (%)	Bulk density ^z (Mg m ⁻³)	Reference field capacity ^z (mm)	Reference wilting point ^z (mm)	Measured available moisture ^y (mm)	Percent of maximum available moisture capacity ^{x,w} (%)
0-25	60.9	15.0	24.1	1.49	63.6	23.3	43.6	100
25-50	66.8	14.9	18.4	1.50	58.3	21.2	28.3	76
50-75	57.8	18.1	24.1	1.45	61.8	23.3	33.2	86
75-100	57.1	19.4	23.5	1.44	60.8	23.3	37.8	100

^z Bulk density, reference field capacity, and wilting point were calculated based on Saxton et al. (1986).

^y Total soil moisture measured after drying at 105 °C minus the reference wilting point.

^x Maximum available moisture capacity = reference field capacity – reference wilting point.

^w Percent of maximum available moisture capacity values greater than 100% were set at 100%.

Results and discussion. Soil moisture content was high when the model was initiated on April 27 and remained close to or above field capacity until the end of June, caused by the precipitation received during this period (Figure 4.17). On July 8, a recommendation to start irrigating on July 12 was given to the producer based on the AIMM simulation. The pivot was started on July 12. A soil moisture sample was taken on July 13 to measure the actual moisture content. The measured available soil moisture content of 70 mm was slightly lower than the AIMM output of 76 mm. The correction was applied to the model (Figure 4.17). The five continuous irrigation circles applied 98 mm of total irrigation water and increased the soil available moisture to 112 mm. Rain in early August caused soil moisture to remain above the irrigation threshold of 77 mm until harvest.

The AIMM program successfully predicted the change in soil moisture at the BDF site in 2010. The timing and volume of irrigation water applied in 2010 was appropriate for the crop and to control irrigation runoff.

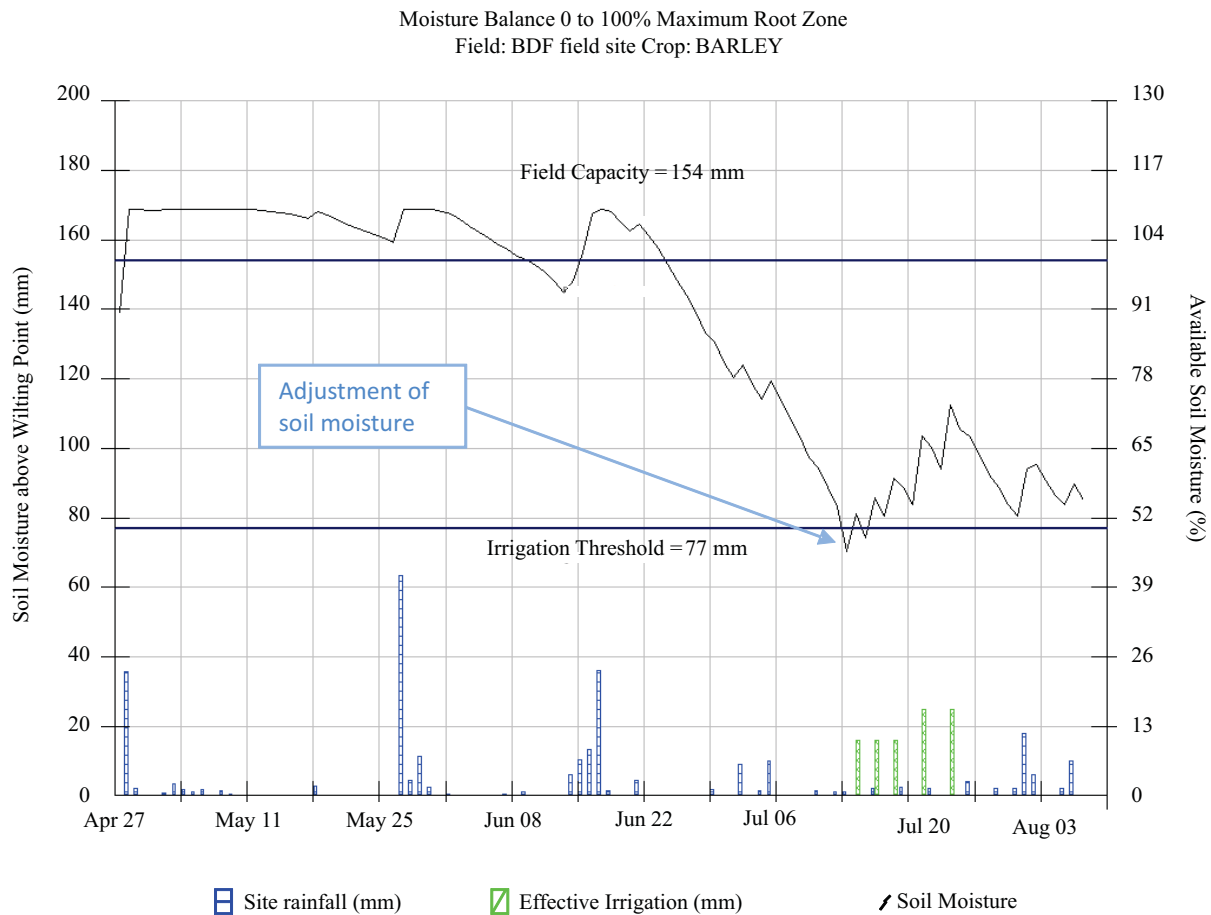


Figure 4.17. Alberta Irrigation Management Model output for the Battersea Drain Field site in 2010.

4.4.3 Cost of Beneficial Management Practices

The costs associated for the implementation of the BMPs at the BDF site were mostly associated to the transportation of the manure to alternative sites located further away from the feedlot and to the modification of the pivot irrigation system modification. Since 2008, the producer has agreed not to apply manure at the BDF site. As a result, the manure that would have been applied to the BDF site had to be transported to alternative sites, which involved greater transportation distances. The cost for manure hauling was calculated based on Toma and Bouma Management Consultants (2006). The initial modification of the pivot irrigation system occurred in 2008, with additional modifications installed in spring 2010.

2008	Soil testing ^z	\$102.75	2 h
	Neutron probe access tube	\$5.00	
	Rain gauges	\$15.00	
	Control panel for pivot	\$8,443.00	3 h
	Control panel installation	\$720.00	
	Manure hauling ^y	\$0.00	
	Sub-total	\$9,285.75	5 h
2009	Soil testing	\$102.75	2 h
	Fertilizer	\$0.00	
	Manure hauling	\$14,842.11	
	BMP maintenance and management	-	2 h
	Sub-total	\$14,944.86	4 h
2010	Pivot modifications - equipment	\$1,501.65	
	Pivot modifications - installation	\$2,220.00	
	Soil testing	102.75	2 h
	Fertilizer	\$0.00	
	Manure hauling	\$15,372.18	
	BMP maintenance and management ^x	-	6 h
	Sub-total	\$19,196.58	8 h
	Grand total	\$43,427.19	17 h

^z Three samples (0-15, 15-30, 30-60 cm) per year, and the cost of analysis was \$34.25 per sample.

^y The 2008 alternative manure application site was located nearby and did not generate additional transportation cost. The 2009 and 2010 cost was based on Toma and Bouma Management Consultants (2006) with an application rate of 87.5 Mg ha⁻¹, 7 km of additional transportation distance, and an annual 4% increase in price.

^x Includes running AIMM and developing a nutrient management plan.

4.5 Soil

4.5.1 Hypothesis

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

4.5.2 Methods

Soil samples collected at the BDF site in 2010 included (1) agronomic soil samples and (2) soil-test samples. Agronomic soil samples were collected on May 26, 2010 after seeding and on October 5, 2010 after all fall field activities were completed. Sampling points were on a 200-m grid covering the area of the BMP site (Figure 4.18). Spring and fall sampling points were positioned in the same locations. The 2010 sampling points were located with the use of a GPS unit and were 5 m east of the 2007 positions. There were a total of 15 sample points. In the spring, 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 (about 1 kg). The sub-samples were air dried, ground (< 2 mm), and sent to the laboratory for analysis. The soil samples were analyzed for extractable nitrate N (NO₃-N), extractable ammonium N (NH₄-N), and STP. The fall agronomic samples were collected on October 5, in conjunction with the soil-test sampling, using a truck-mounted hydraulic coring unit.

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.

The soil-test sampling was carried on October 5, 2010. Due to time constraints, samples were collected using the 200- by 200-m agronomic grid rather than transects used in the previous years (Figure 4.18). 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 0- to 60-cm core at each grid sampling point in three increments: 0 to 15 cm, 15 to 30 cm, and 30 to 60 cm. Samples from the 15 sampling points were mixed together per incremental layer and sub-sampled (about 1 kg). The sub-samples were then air dried, ground (< 2 mm), and sent to the laboratory for analysis. The soil samples were analyzed for extractable NO₃-N, extractable NH₄-N, and STP.

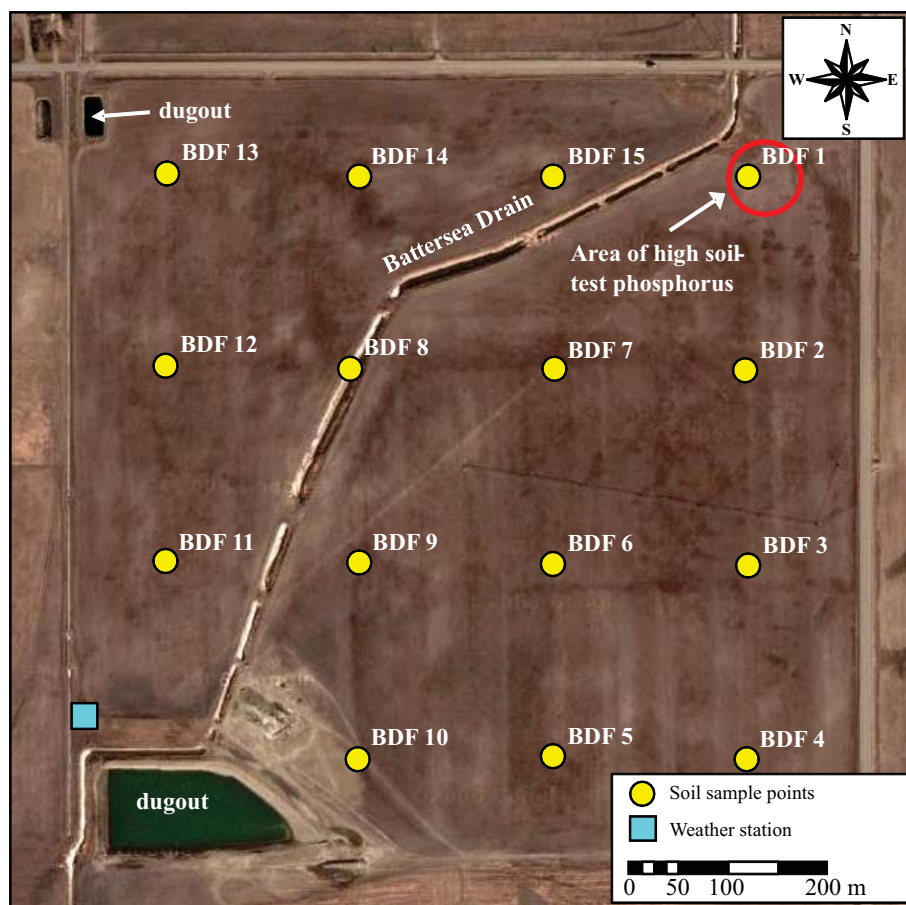


Figure 4.18. Soil sampling points at the Battersea Drain Field site.

4.5.3 Results and Discussion

Results from the agronomic soil samples in 2010 for $\text{NH}_4\text{-N}$ and STP were generally similar to the previous years (Table 4.3). However, $\text{NO}_3\text{-N}$ concentrations in 2010 were less than one-third of the concentrations measured during the previous 3 yr. Nitrate N concentrations in 2010 also generally followed the trend from previous years, with lower concentrations measured in the fall compared to the spring. There were no consistent trends for $\text{NH}_4\text{-N}$ or STP with time. Average STP concentration in spring 2010 was the highest recorded since the start of the study at 509 mg kg^{-1} , which is more than eight-fold higher than the agronomic threshold of 60 mg kg^{-1} . One of the sample points (BDF1) in this field had a particularly high STP concentration of 1300 mg kg^{-1} in the spring and a concentration of 1120 mg kg^{-1} in fall 2010 (Figure 4.18), and this contributed to the high average concentration in spring 2010. Soil-test P values at this site have been consistently high during the study period ranging from 790 to 1300 mg kg^{-1} . The reason why this sampling point has consistently high STP value is unclear. Conversations with the landowner have eliminated past manure stockpiling as a possible cause. However, this area of the field can have excessive water and cause poor crop growth, or in some years, not seeded because of wet conditions. Reduced or no crop growth would result in less P uptake and greater amounts of P accumulated in the soil.

Comparisons of the pre- and post-BMP phases indicated that spring $\text{NO}_3\text{-N}$ concentrations were significantly reduced from the pre-BMP phase to the post-BMP phase (Table 4.4). Nitrate-N concentration in the fall was also lower in the post-BMP phase compared to the pre-BMP phase; however, the difference was not statistically significant. Ammonia-N concentrations were significantly decreased in spring and fall post-BMP phase and there were no significant changes in STP concentrations from pre- to post-BMP phase. These preliminary results suggest that the null hypothesis can be rejected regarding $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$, which were reduced in concentration after the cessation of manure. Soil-test P, in contrast, was not significantly impacted after the cessation of manure for 2 yr. This is not entirely unexpected due the residual effect of heavy manure application for several years and that P is relatively immobile and remains near the soil surface. Additional time is required to determine if STP concentration will decrease by crop removal with continued cession of manure application.

Soil-test sample results in fall 2010 were used to development a nutrient management plan for 2011. The intended crop in 2011 is potato. Current soil nutrient status for N is considered medium (Table 4.5) for potatoes and the recommendation is 168 to $179 \text{ kg ha}^{-1} \text{ N}$ (ARD 2005). There is no additional requirement for P for the BDF site.

Table 4.3. Average nitrate nitrogen ($\text{NO}_3\text{-N}$), ammonium nitrogen ($\text{NH}_4\text{-N}$), and soil-test phosphorus (STP) concentrations for the agronomic soil samples collected from 2007 to 2010 at the Battersea Drain Field site.

Season and year	$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$ (mg kg^{-1})	STP
Spring 2007	36	5	328
Fall 2007	24	49	349
Spring 2008	73	9	356
Fall 2008	38	4	475
Spring 2009	38	3	347
Fall 2009	40	4	432
Spring 2010	14	5	509
Fall 2010	10	3	436

Table 4.4. Pre-BMP (2007 and 2008) and post-BMP (2009 and 2010) phase comparison of average nitrate nitrogen (NO₃-N), ammonium nitrogen (NH₄-N), and soil-test phosphorus (STP) concentrations in the agronomic soil samples from the Battersea Drain Field site.

Phase	NO ₃ -N	NH ₄ -N (mg kg ⁻¹)	STP
Spring pre-BMP	54 ^a	7 ^a	342
Spring post-BMP	26 ^b	4 ^b	428
Fall pre-BMP	31	27 ^a	412
Fall post-BMP	28	4 ^b	434

^a Average concentrations per parameter and season followed by letters are significantly different at $P < 0.10$.

Table 4.5. Soil-test results for nitrate nitrogen (NO₃-N), ammonium nitrogen (NH₄-N), and soil-test phosphorus (STP) for samples collected on October 5, 2010.

Soil layer (cm)	NO ₃ -N	NH ₄ -N (mg kg ⁻¹)	STP
0 to 15	13	5	401
15 to 30	6	2	161
30 to 60	3	1	26

4.6 Water Flow and Quality

4.6.1 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, pivot modification, and irrigation scheduling) will have no effect on water quality parameter concentrations in runoff at this site. A second null hypothesis is that the implementation of pivot modification and irrigation scheduling BMPs will have no effect on the amount of edge-of-field run generated by irrigation.

4.6.2 Methods

Six water monitoring stations were established at the BDF site. Two were instream stations upstream (Station 201) and downstream (Station 202) in the Battersea Drain (Figure 4.1). The other four stations were edge-of-field stations: two located on either side of the Battersea Drain near the northeast corner of the site (Stations 203 and 204) and two on either side of the drain near the southwest corner of the site (Stations 205 and 206). Most of the runoff at the BDF site drains through these four edge-of-field stations directly into Battersea Drain. Each edge-of-field station was equipped with a circular flume and an Isco water sampler. The upstream Station 201 and downstream Station 202 were equipped with a staff gauge and an Isco sampler. Station 202 was also equipped with an Argonaut SW for direct flow measurements. Flow was not estimated at the upstream station because it was assumed that differences in flow between the two instream stations, separated by about 950 m, were less than the flow measurement error. Outside of the irrigation season, the flow in the drain was too low to be measured by the Argonaut SW. Low flow was estimated based on previous long-term monitoring at this site.

The system was designed so that the four edge-of-field stations were masters to the two instream stations. Water samples were collected by the Isco samplers during all runoff events detected at an edge-of-field station, which simultaneously triggered both instream water

monitoring stations to sample. Furthermore, grab samples were also taken from the two instream stations bi-weekly during the irrigation season (May to October) and monthly during the rest of the year unless runoff was observed during the scheduled sampling day.

Runoff events were characterized as snowmelt, rainfall, irrigation, or combined irrigation and rainfall. The last category was defined as a runoff event occurring when a minimum 20 mm of rainfall occurred during irrigation. Combination events with < 20 mm of rainfall were classified as irrigation.

A channel that was trenched from the quarter section south of Station 205 was observed on June 3, 2010 (Figure 4.13b). It was assumed that this was constructed to drain pooled runoff water from this field that was caused by the late May rainfall events. This trench remained there until the fields were harvested in the fall. Samples collected at Station 205 in June and July were affected by runoff from this south field after the trench was dug. These samples were not included in the data analysis.

Daily loads were determined by multiplying the total volume by the water quality concentrations in the sample collected that day. Flow on days when no samples were collected was added to the closest day that did have a sample collected in order to account for this flow. Total annual loads were the sum of all the daily loads. Greater than normal precipitation occurred in April, May, and June in 2010 (Figure 4.3b) and high instream flow levels caused significant water from the drain to back-up into the flumes at Stations 204, 205, and 206. The flow measurement during periods when back-up was observed in flumes was omitted from total flow and loading calculations for the edge-of-field stations. No water samples were collected from the edge-of-field stations when the drain backed-up into the flumes.

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. Due to the larger variation in water quality parameter concentrations caused by flow conditions rather than event types (snowmelt, rainfall, and irrigation), the water quality data at the instream stations (Stations 201 and 202) were grouped by flow conditions. High flow events in the Battersea Drain occur when source water was running through the irrigation delivery system, and this corresponded to the growing season period (approximately mid May to mid October). Low flow events in the Battersea Drain occurred outside of the growing season when the irrigation source water was turned off. The pre-BMP phase included data from March 14, 2007 to October 8, 2008 and the post-BMP phase included data from October 15, 2008 to December 15, 2010.

Water quality parameters were compared between the upstream and downstream stations using samples collected on the same day at both stations. Since water quality concentrations data at the two stations are not independent of one another, a single population was created using data from both stations by subtracting the upstream concentration from the downstream concentration to create one difference value for each sampling day. Statistical comparisons were made by comparing these differences for each event type and all events combined in the pre-BMP and post-BMP phases. The Univariate procedure in SAS was used to test the distribution of the data and the Means procedure was used to generate descriptive statistics. The pre-BMP and post-BMP implementation differences were tested using the Least Squared Means test in the Mixed procedure with variance components, as the variance structure, and the repeated and pdiff options. A significance level of $P < 0.10$ was used in this study.

4.6.3 Results and Discussion

4.6.3.1 Flow Volumes

The total volume of water measured at the downstream Station 202 was 5,814,602 m³ in 2010. This amount was within the range measured during the previous 3 yr of 4.9 to 6.4 million m³ yr⁻¹. More than 90% of the total flow volume occurred from mid April to mid October in 2010 (Figure 4.19), which was also similar to the previous 3 yr (Olson and Kalischuk 2010). The initial increase in flow volume in the spring was caused by snow and ice melting in the drain. High flow in the drain during the growing season was sustained by water flowing for irrigation and field runoff (Olson and Kalischuk 2008, 2009). In 2010, however, less irrigation source water (on average, 0.48 m³ s⁻¹ in May and 0.42 m³ s⁻¹ in June) was released from the Picture Butte Reservoir in May and June than in previous years (Ryan Chogi, Water Master with the Lethbridge Northern Irrigation District, personal communication). After the irrigation flow ceased in early October, the flow quickly decreased in the drain in all 4 yr. Low flow volumes generally occurred during the non-irrigation season from shallow groundwater discharge. Flow rates ranging from 0.01 to 0.02 m s⁻¹ were estimated for the low flow periods, except when runoff events occurred.

Snowmelt runoff occurred from January 12 to March 19 and caused the majority of flow at Station 206 in 2010 (Table 4.6; Figure 4.20d). Rainfall events from April 14 to June 17 caused the majority of the runoff at Stations 203, 204, and 205 in 2010 (Figure 4.20a-c). No irrigation runoff was measured at Stations 203, 204, and 206 in 2010. In contrast to the previous 3 yr, from the end of May until mid August, the irrigation runoff flow was observed at Stations 204, 205, and 206 in regular cycles as the pivot irrigation system passed over these edge-of-field sites (Olson and Kalischuk 2010).

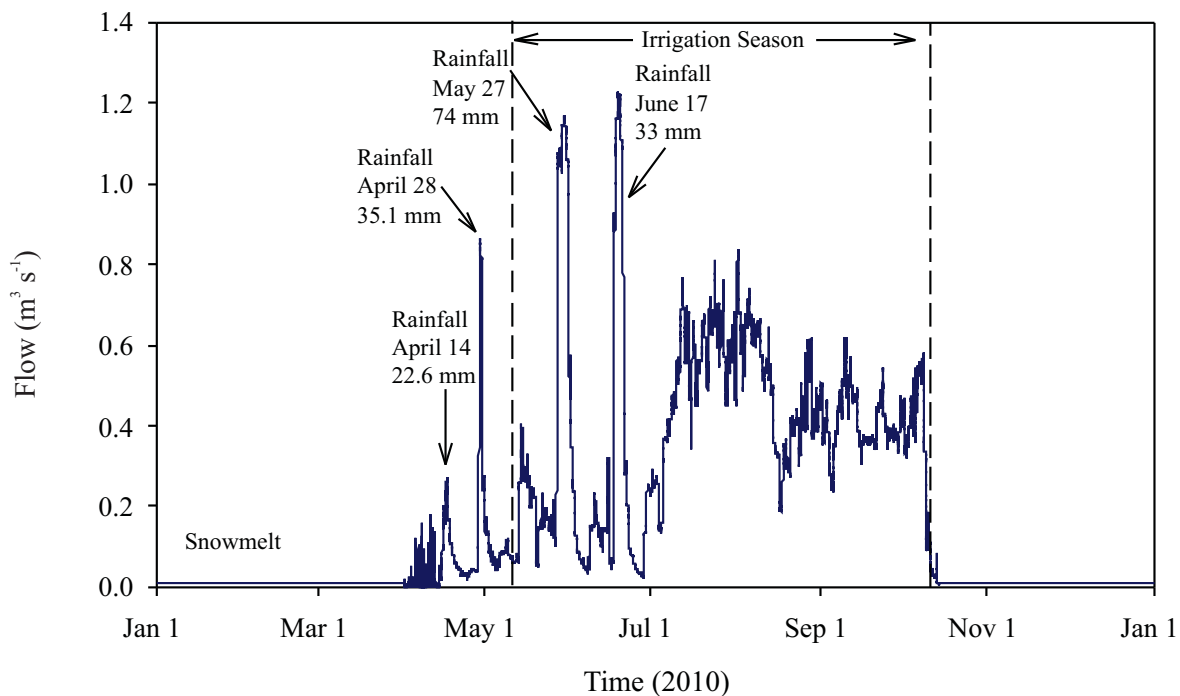


Figure 4.19. Hydrograph for the downstream Station 202 at the Battersea Drain Field site in 2010.

As discussed in Sub-section 4.4.2.1, the BMP was successful at eliminating irrigation runoff at Station 206 but not at Station 205, and this was likely because of the excess of water draining from the south field and from the water backed-up from Battersea Drain. It is not clear if irrigation runoff occurred at Station 204 in 2010 because the station was submerged by the excess of water from Battersea Drain during the irrigation period.

Total flow volume at the edge-of-field stations in 2010 was 13,798 m³, which was two- to six-fold larger than measured in the previous 3 yr (Table 4.6). However, the runoff volume in 2007 was likely underestimated because flow measurements were not taken prior to late June because of a delay in instrumentation installation, and as a result, snowmelt and rainfall runoff may have been missed. Even though the total edge-of-field runoff volume was larger in 2010, this volume was still small (0.32%) compared to the volume in the drainage channel, and this is consistent with the previous years, which ranged from 0.03 to 0.15% (Olson and Kalischuk 2010).

4.6.3.2 Instream Monitoring Stations Water Quality

All instream water quality parameter average concentrations, with the exception of total suspended solids (TSS) and *Escherichia coli* (*E. coli*), were higher in 2010 compared with the previous 3 yr (Table 4.7). Generally, N parameters and electrical conductivity (EC) average concentrations were higher at the downstream station compared with the upstream station; whereas, P parameters, TSS, and *E. coli* average concentrations were higher at the upstream station than at the downstream station in all 4 yr.

Table 4.6. Edge-of-field station annual flow and proportions of flow as snowmelt, rainfall, irrigation, and irrigation/rainfall runoff.

Station	Year	Flow (m ³)	% Snowmelt	% Rainfall	% Irrigation	% Irrigation/rainfall
203	2007 ^z	0	0	0	0	0
204	2007	953	0	0	100	0
205	2007	907	0	0	100	0
206	2007	376	0	0	100	0
203	2008	556	9	48	43	0
204	2008	2701	0	30	69	1
205	2008	4102	0	25	74	0
206	2008	1459	15	21	65	0
203	2009	487	47	27	16	11
204	2009	1209	7	35	12	46
205	2009	4688	8	43	9	41
206	2009	411	19	64	14	3
203	2010	2413	13	87	0	0
204	2010	4356	8	92	0	0
205 ^y	2010	4246	9	86	2	0
206	2010	2783	58	42	0	0

^z No snowmelt or rainfall runoff flow data were collected in 2007 because the flow instrumentation was not installed until late in June 2007.

^yA trench was observed on June 3 from the quarter section south of the Battersea Drain Field site and this affected runoff at Station 205 from the first week of June until harvest. This runoff was not included in the water analyses. Runoff volumes specifically attributed from the south quarter section equaled 4% of total volume for this site in 2010.

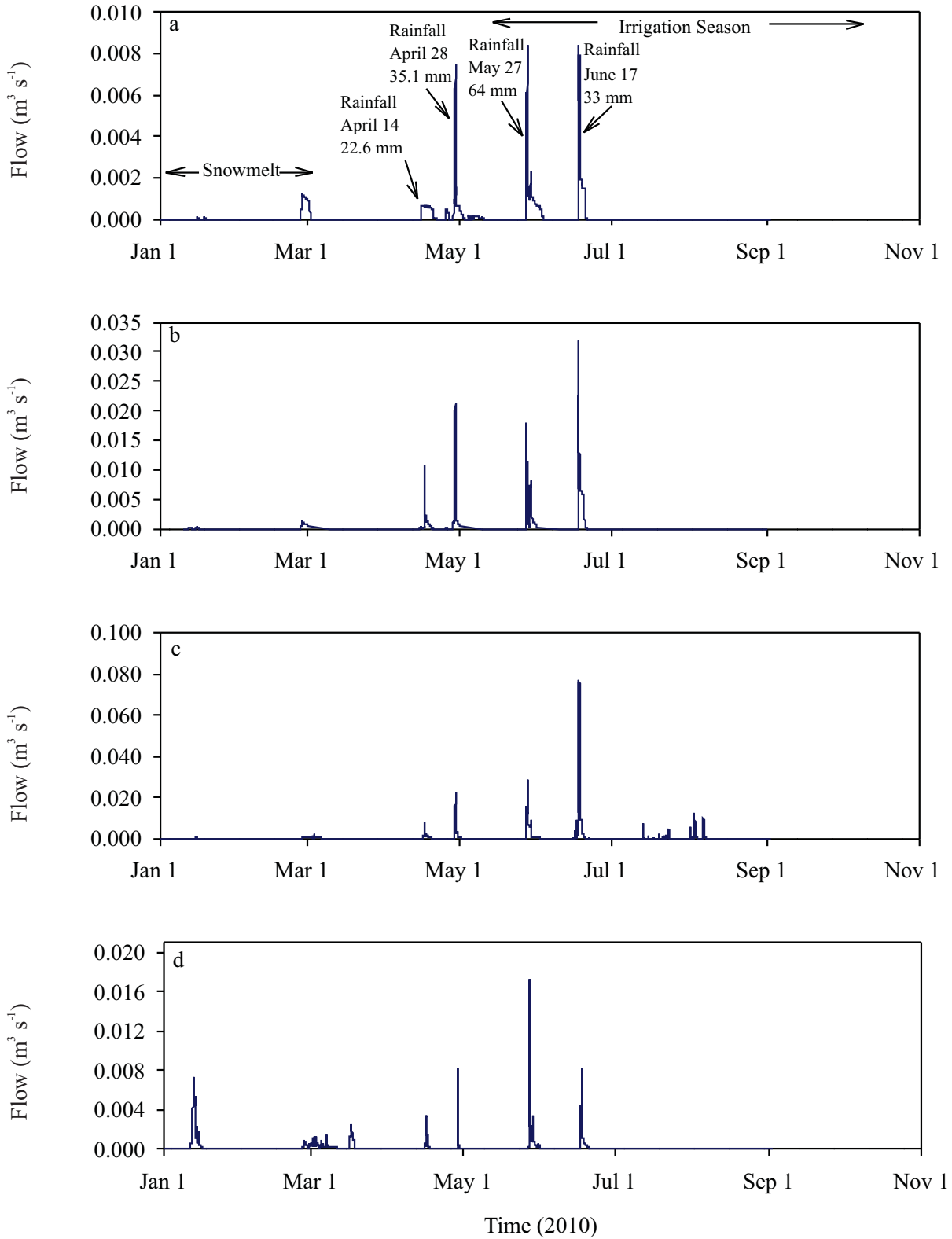


Figure 4.20. Hydrographs of the four edge-of-field water monitoring stations at the Battersea Drain Field site in 2010 at (a) Station 203, (b) Station 204, (c) Station 205, and (d) Station 206.

Table 4.7. Average water quality parameters at Stations 201 (upstream) and 202 (downstream) at the Battersea Drain Field site from 2007 to 2010.^z

Year ^y	TN	ON	NO ₃ -N	NH ₃ -N	TP	TDP	PP	TSS	<i>E. coli</i>	EC
	----- (mg L ⁻¹) -----								(mpn 100 mL ⁻¹)	(µS cm ⁻¹)
<i>Station 201</i>										
2007 (32)	0.77	0.52	0.13	0.10	0.08	0.04	0.04	21	228	523
2008 (46)	1.43	1.18	0.10	0.12	0.28	0.10	0.19	66	1809	667
2009 (43)	1.54	0.91	0.42	0.18	0.19	0.11	0.08	23	736	719
2010 (55)	4.60	1.72	1.76	1.04	0.93	0.63	0.30	50	1474	1143
<i>Station 202</i>										
2007 (32)	3.23	0.63	2.43	0.13	0.08	0.03	0.03	12	231	620
2008 (46)	3.53	1.06	2.29	0.14	0.19	0.09	0.11	47	1455	721
2009 (43)	3.61	0.93	2.46	0.17	0.15	0.10	0.05	13	604	767
2010 (55)	7.49	1.70	4.58	1.08	0.86	0.62	0.24	34	491	1243

^z TN = total nitrogen, ON = organic nitrogen, NO₃-N = nitrate nitrogen, NH₃-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 Number of samples are shown in parenthesis.

In 2010, TN and NO₃-N concentrations were similar between the two monitoring stations from mid April to late September (Figure 4.21a,c). However, after the irrigation infrastructure quit delivering water at the beginning of October, TN increased from 0.24 mg L⁻¹ on September 28 to 22.4 mg L⁻¹ on November 9 at the downstream station. In contrast, a similar increase was not observed in the upstream station, suggesting N loading from the adjacent land to the drain. During the period outside of the irrigation season, flow in the drain was low and maintained by discharge from shallow groundwater. This suggests that the groundwater has high N concentration and is a source within the reach of the drain between the two monitoring stations. The high rates of manure spreading have resulted in an excessive accumulation of nutrients, including NO₃-N, and this is the likely source to the local groundwater. Typically, much larger volumes of irrigation water flows through the drain in the irrigation season, and the N is diluted (Olson and Kalischuk 2010). The greater volume of water in the drain may recharge into the local groundwater, and thus, groundwater with high N concentration may not enter the drain during this time period. However, in 2010, there was less irrigation source water in the drain from mid April until mid June because of extensive rainfall (Ryan Chogi, Water Master with the Lethbridge Northern Irrigation District, personal communication). As a result, there may have been a higher portion of water in the drain from surface runoff caused by the rainfall during this period. With less irrigation source water to cause dilution and an increase in surface runoff may have been the main reasons for higher concentrations of many instream water quality parameters in 2010 compared to the previous 3 yr. Larger contributing land area and greater surface water interactions with shallow groundwater likely caused TN, ON, NO₃-N, and NH₃-N peaks to occur at both instream stations during rainfall runoff events in 2010 (Figure 4.21).

Total phosphorus (TP) and total dissolved phosphorus (TDP) peak concentrations corresponded to the snowmelt events in January, February, and March 2010 and to the rainfall events from mid April to mid June (Figure 4.22a,b). Particulate phosphorus (PP) and TSS concentrations were highest on February 22 at the upstream station (Figure 4.22c). The upstream PP concentrations remained high during snowmelt at the beginning of March. Particulate P and TSS peaks at both stations corresponded to the rainfall events from mid April to mid June.

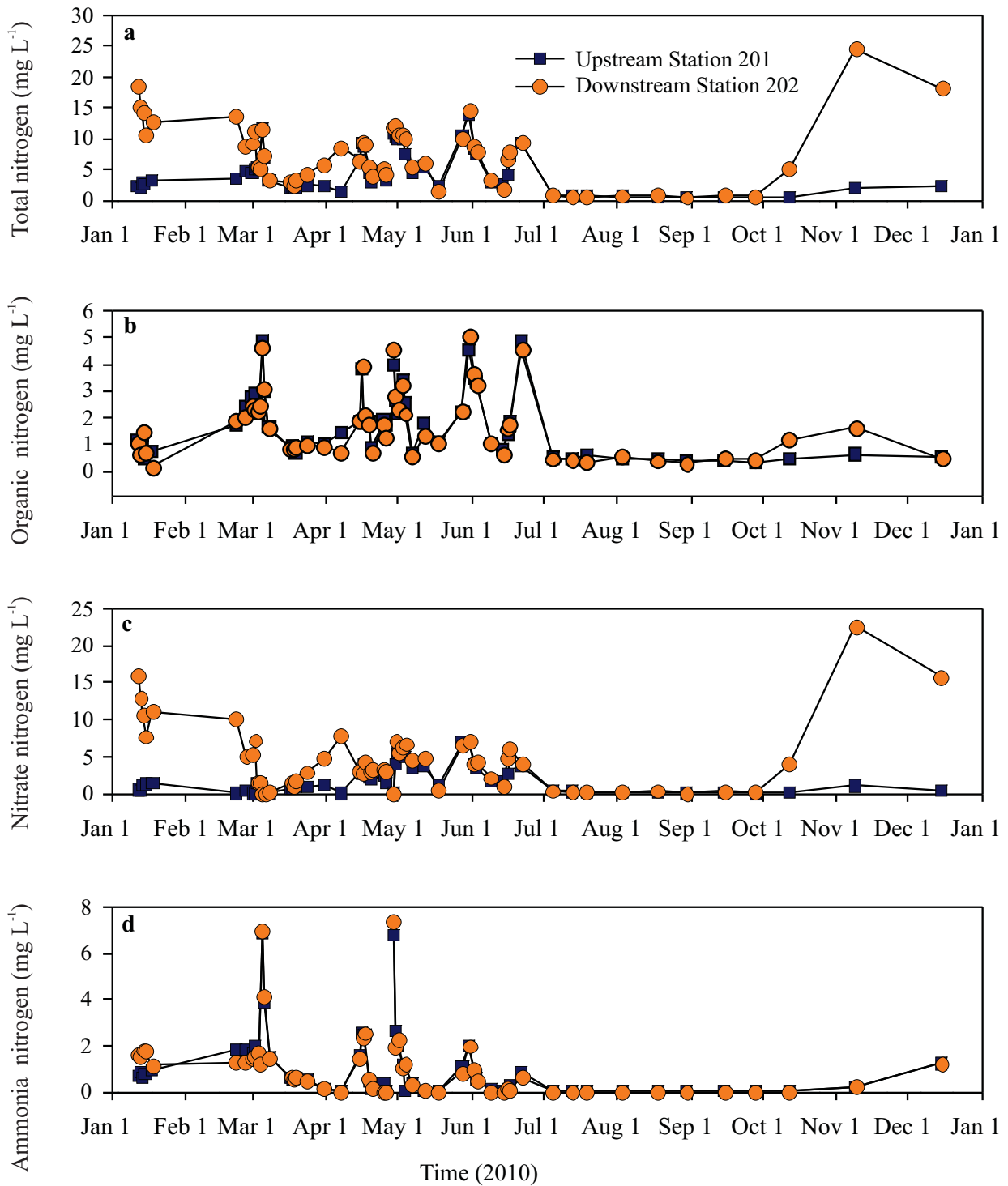


Figure 4.21. Concentration values for (a) total nitrogen, (b) organic nitrogen, (c) nitrate nitrogen, and (d) ammonia nitrogen at the upstream Station 201 and downstream Station 202 at the Battersea Drain Field site in 2010.

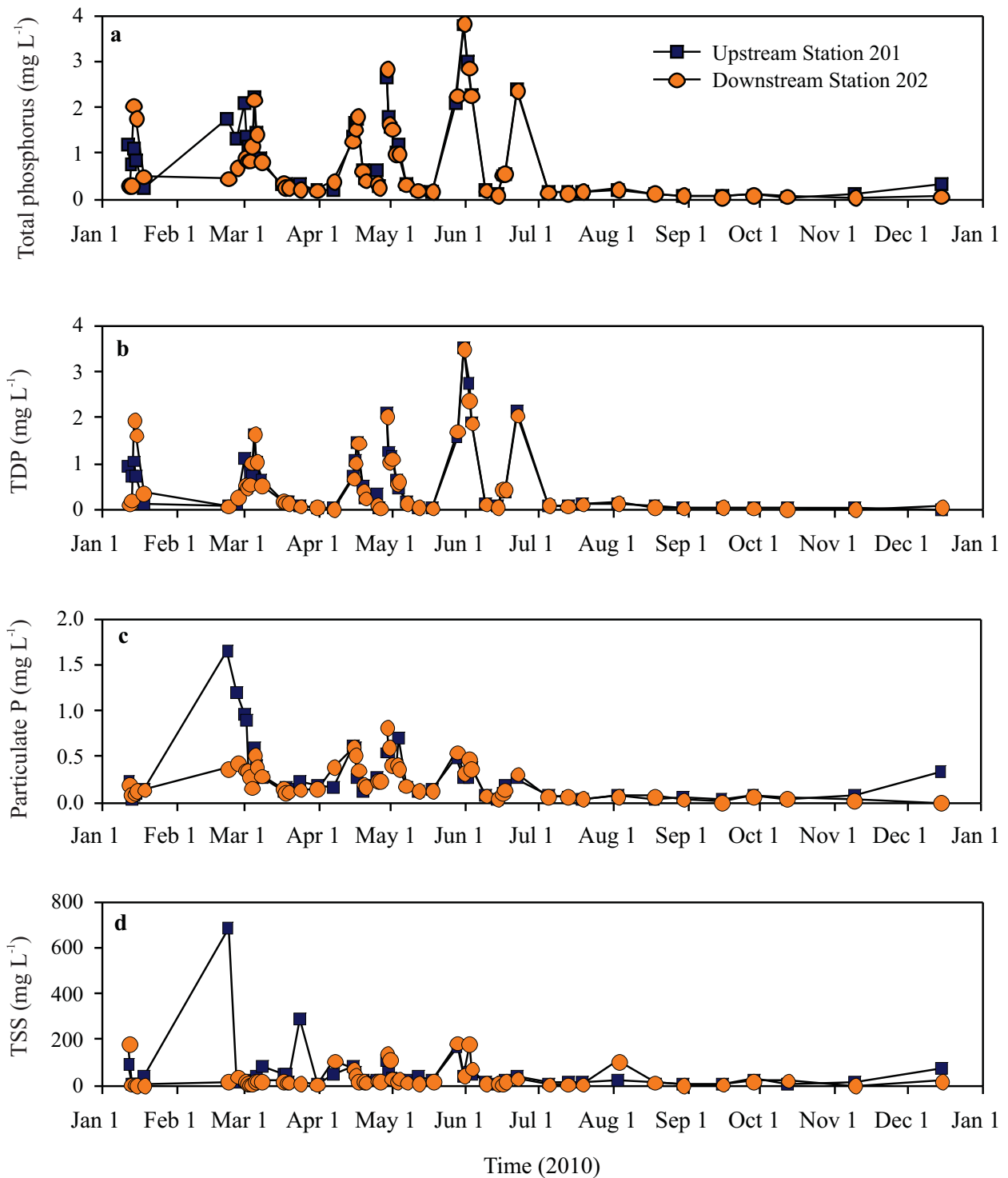


Figure 4.22. Concentration values for (a) total phosphorus, (b) total dissolved phosphorus (TDP), (c) particulate phosphorus, and (d) total suspended solids (TSS) at the upstream Station 201 and downstream Station 202 at the Battersea Drain Field site in 2010.

Concentration of *E. coli* in 2010 ranged from 0.5 to 59,540 mpn 100 mL⁻¹ at the upstream station and from 0.5 to 6570 mpn 100 mL⁻¹ at the downstream station (Figure 4.23). Main peak concentrations occurred in mid and late April and in late May. The high concentration at the upstream in late May was the highest value recorded at the instream sites in 4 yr of monitoring. A similarly high value of 39,000 mpn 100 mL⁻¹ was observed at this station in 2008. The main rainfall events in 2010 occurred from mid April to mid June (Figure 4.4), and this may have caused the large increases in *E. coli*. Higher *E. coli* concentrations were also linked with heavy rainfall events in 2008 (Olson and Kalischuk 2009). In 2007, there was a lack of heavy rainfall events throughout the growing season and *E. coli* concentrations ranged from 0.5 to 1000 mpn 100 mL⁻¹ (Olson and Kalischuk 2008).

Instream loads were greater in 2010 compared with the previous 3 yr for all water quality parameters during high flows and for all flows combined (Table 4.8). Low-flow loads in 2010 were less for TN, ON, and NO₃-N and were greater for TP and TDP compared with the other 3 yr. The low-flow period was not as long in 2010, as the high flow period started earlier due to rainfall in mid April and typically this low-flow period is when NO₃-N and TN are highest at the downstream station (Table 4.7).

Overall in 2010, when the downstream station is compared to the upstream station, TN, NO₃-N, NH₃-N, and EC concentrations were higher at the downstream station. However, ON, TP, TDP, PP, TSS, and *E. coli* concentrations were higher at the upstream station.

4.6.3.3 Edge-of-field Monitoring Stations Water Quality

Total dissolved P was the dominant form of P at all four edge-of-field stations in 2010 (Table 4.9), and this was consistent with the previous 3 yr (Tables 4.10 to 4.12). Organic N (ON) was the dominant N form at Stations 203 and 206, but NO₃-N was the dominant form at Stations 204 and 205 in 2010. Generally, NO₃-N, NH₃-N, and PP were minor components and ON the dominant form in the first 3 yr of the study at all four edge-of-field stations (Tables 4.10 to 4.12). The highest average TN, ON, NH₃-N, TP, TDP, and EC concentrations occurred at Station 204 and the highest average NO₃-N and TSS concentrations occurred at Station 205 in 2010. Nitrogen concentrations at Stations 204 and 205 behaved similarly in 2010 as TN and NO₃-N were higher in rainfall runoff and ON and NH₃-N were higher in snowmelt at both stations. The TN and NO₃-N concentrations were similar during snowmelt and rainfall runoff at Stations 204 and 205. Interestingly, with the excessive rainfall runoff in 2010, back-up flow from the drain affected

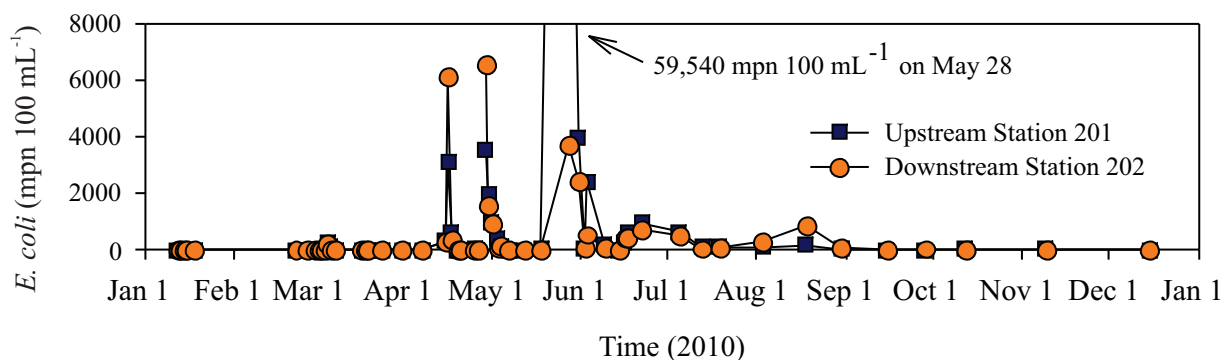


Figure 4.23. Concentration values for *Escherichia coli* (*E. coli*) at the upstream Station 201 and downstream Station 202 at the Battersea Drain Field site in 2010.

Table 4.8. Load values for nutrients and total suspended solids at the downstream water monitoring station (Station 202) at the Battersea Drain Field site from 2007 to 2010.^z

Year	TN	ON	NO ₃ -N	NH ₃ -N	TP	TDP	PP	TSS
----- (kg) -----								
<i>Low flow</i>								
2007	3100	623	2314	130	54	14	40	10,337
2008	6680	816	5610	168	61	12	49	127,534
2009	2995	260	2538	147	53	31	22	6580
2010	2472	377	1962	110	64	30	34	8731
<i>High flow</i>								
2007	2508	1981	203	174	294	126	97	46,703
2008	4586	3706	552	182	599	305	311	54,615
2009	3653	2884	510	142	379	235	144	49,435
2010	16345	6580	7518	1898	3621	2913	708	205,325
<i>Overall</i>								
2007	5608	2603	2517	304	348	140	136	57,040
2008	11,267	4522	6162	350	660	317	359	182,149
2009	6648	3143	3048	289	432	266	166	56,015
2010	18,818	6957	9480	2008	3686	2944	742	214,056

^z TN = total nitrogen, ON = organic nitrogen, NO₃-N = nitrate nitrogen, NH₃-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids.

Table 4.9. Average water quality parameters for the four edge-of-field water monitoring stations (Stations 203, 204, 205, and 206) at the Battersea Drain Field site in 2010.^z

Station ^y	TN	ON	NO ₃ -N	NH ₃ -N	TP	TDP	PP	TSS	<i>E. coli</i>	EC
----- (mg L ⁻¹) -----									(mpn 100 mL ⁻¹)	(µS cm ⁻¹)
<i>2010 snowmelt</i>										
203 (2)	3.24	2.57	0.31	0.34	2.88	2.57	0.32	17	1	334
204 (5)	9.93	4.81	3.33	1.44	6.28	5.98	0.30	12	42	2345
205 (13)	7.53	1.85	4.95	0.52	1.27	1.08	0.19	20	2	1031
206 (11)	3.12	2.29	0.49	0.24	3.03	2.88	0.15	10	91	461
<i>2010 rainfall</i>										
203 (19)	2.98	2.61	0.29	0.05	3.39	3.31	0.09	12	44	2523
204 (10)	10.77	3.87	6.66	0.21	5.09	4.88	0.21	14	26	4180
205 (9)	11.91	1.09	10.65	0.11	1.29	1.21	0.08	32	90	2309
206 (5)	3.21	1.97	1.11	0.09	3.66	3.35	0.31	32	32	435
<i>2010 all</i>										
203 (21)	3.00	2.61	0.29	0.07	3.34	3.24	0.11	12	40	2315
204 (15)	10.49	4.18	5.55	0.62	5.49	5.25	0.24	13	31	3568
205 (22)	9.32	1.54	7.29	0.35	1.28	1.13	0.15	24	38	1554
206 (16)	3.15	2.19	0.69	0.20	3.23	3.03	0.20	17	72	453

^z TN = total nitrogen, ON = organic nitrogen, NO₃-N = nitrate nitrogen, NH₃-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 Number of samples are shown in parenthesis.

Table 4.10. Average water quality parameters for the four edge-of-field water monitoring stations (Stations 203, 204, 205, and 206) at the Battersea Drain Field site in 2009.^z

Station ^y	TN	ON	NO ₃ -N	NH ₃ -N	TP	TDP	PP	TSS	<i>E. coli</i> (mpn 100 mL ⁻¹)	EC (µS cm ⁻¹)
(mg L ⁻¹)										
<i>2009 snowmelt</i>										
203 (4)	2.64	2.12	0.06	0.43	1.56	1.37	0.19	42	1	498
204 (1)	8.48	6.89	1.43	0.13	6.88	6.84	0.04	2	1	7030
205 (7)	4.74	2.82	0.49	1.40	0.98	0.90	0.07	11	17	996
206 (7)	5.81	4.75	0.34	0.63	6.52	6.09	0.43	12	20	444
<i>2009 rainfall</i>										
203 (3)	3.90	3.78	0.05	0.05	3.00	2.89	0.11	11	1901	2477
204 (5)	9.43	6.90	2.38	0.13	4.97	4.86	0.11	6	1431	4472
205 (7)	6.91	2.91	3.89	0.06	2.13	1.84	0.29	98	1353	1034
206 (2)	4.44	4.17	0.22	0.03	6.29	6.20	0.09	28	1234	541
<i>2009 irrigation</i>										
203 (0)	ns ^x	ns	ns	ns	ns	ns	ns	ns	ns	ns
204 (4)	12.05	7.35	4.44	0.10	4.72	4.44	0.28	13	746	4318
205 (6)	3.23	3.16	0.03	0.03	2.16	2.01	0.15	15	2048	901
206 (2)	3.17	3.10	0.03	0.03	5.08	4.97	0.12	19	7700	567
<i>2009 irrigation/rainfall</i>										
203 (2)	6.05	4.31	1.53	0.04	3.15	3.00	0.15	7	750	2775
204 (2)	12.26	5.44	6.71	0.09	5.51	5.47	0.05	18	425	4125
205 (4)	4.07	3.09	0.76	0.13	3.25	2.75	0.49	605	1680	929
206 (1)	6.93	5.52	1.25	0.03	8.62	8.44	0.18	10	240	846
<i>2009 all</i>										
203 (9)	3.82	3.16	0.39	0.22	2.40	2.24	0.16	24	800	1663
204 (12)	10.70	7.22	3.71	0.11	5.14	4.99	0.15	10	916	4576
205 (24)	4.89	2.97	1.41	0.45	1.99	1.76	0.23	136	1192	972
206 (12)	5.24	4.44	0.35	0.38	6.42	6.12	0.30	16	1521	514

^z TN = total nitrogen, ON = organic nitrogen, NO₃-N = nitrate nitrogen, NH₃-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 Number of samples are shown in parenthesis.

^x No samples.

Table 4.11. Average water quality parameters for the four edge-of-field water monitoring stations (Stations 203, 204, 205, and 206) at the Battersea Drain Field site in 2008.^z

Station ^y	TN	ON	NO ₃ -N	NH ₃ -N	TP	TDP	PP	TSS	<i>E. coli</i>	EC
	----- (mg L ⁻¹) -----								(mpn 100 mL ⁻¹)	(µS cm ⁻¹)
<i>2008 snowmelt</i>										
203 (3)	2.51	2.08	0.36	0.05	3.28	3.19	0.09	9	1	745
204 (0)	ns ^x	ns	ns	ns	ns	ns	ns	ns	ns	ns
205 (1)	3.25	3.18	0.03	0.03	0.90	0.61	0.29	200	1	1410
206 (3)	2.62	2.23	0.13	0.24	2.30	2.25	0.05	7	2	328
<i>2008 rainfall</i>										
203 (10)	4.53	4.42	0.04	0.04	4.03	3.75	0.29	5	321	3428
204 (14)	8.00	7.14	0.64	0.17	6.05	5.93	0.13	10	2269	3084
205 (11)	11.64	6.48	4.49	0.35	3.16	2.94	0.21	19	1069	1719
206 (10)	18.32	16.27	0.71	1.28	13.48	12.80	0.68	18	3490	1219
<i>2008 irrigation</i>										
203 (3)	5.79	5.25	0.36	0.09	3.71	3.42	0.29	48	13,800	4323
204 (8)	6.23	5.75	0.32	0.12	4.45	4.02	0.43	79	9693	2096
205 (7)	2.96	2.87	0.04	0.03	1.49	1.18	0.31	73	2274	1009
206 (6)	4.25	4.15	0.04	0.04	7.25	6.73	0.52	27	1335	701
<i>2008 irrigation/rainfall</i>										
203 (0)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
204 (1)	5.93	5.46	0.30	0.14	5.82	5.62	0.20	9	2800	2520
205 (2)	2.95	2.86	0.03	0.04	3.02	2.71	0.31	13	3795	1085
206 (0)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
<i>2008 all</i>										
203 (16)	4.39	4.13	0.16	0.05	3.83	3.58	0.25	14	2788	3093
204 (23)	7.29	6.58	0.51	0.15	5.49	5.25	0.23	34	4655	2716
205 (21)	7.52	4.77	2.36	0.20	2.48	2.22	0.26	45	1649	1407
206 (19)	11.40	10.23	0.41	0.72	9.75	9.22	0.53	19	2310	915

^z TN = total nitrogen, ON = organic nitrogen, NO₃-N = nitrate nitrogen, NH₃-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 Number of samples are shown in parenthesis.

^x No samples.

Table 4.12. Average water quality parameters for the four edge-of-field water monitoring stations (Stations 203, 204, 205, and 206) at the Battersea Drain Field site in 2007.^z

Station ^y	TN	ON	NO ₃ -N	NH ₃ -N	TP	TDP	PP	TSS	<i>E. coli</i> (mpn 100 mL ⁻¹)	EC (μS cm ⁻¹)
(mg L ⁻¹)										
<i>2007 rainfall</i>										
203 (1)	2.21	2.00	0.08	0.10	2.32	2.23	0.09	6	0.5	868
204 (1)	17.9	6.80	10.8	0.12	6.31	6.20	0.11	4	0.5	4140
205 (2)	11.8	2.74	8.89	0.12	0.69	0.49	0.20	5	2.0	2115
206 (0)	ns ^x	ns	ns	ns	ns	ns	ns	ns	ns	ns
<i>2007 irrigation</i>										
203 (0)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
204 (6)	3.54	3.25	0.20	0.07	3.02	2.71	0.31	41	4981	1492
205 (9)	3.85	3.02	0.59	0.16	1.01	0.43	0.57	281	4471	884
206 (8)	2.83	2.61	0.10	0.09	2.01	1.83	0.19	35	2234	535
<i>2007 all</i>										
203 (1)	2.21	2.00	0.08	0.10	2.32	2.23	0.09	6	1	868
204 (7)	5.59	3.75	1.71	0.08	3.49	3.20	0.28	36	4270	1870
205 (11)	5.29	2.97	2.10	0.15	0.95	0.44	0.51	231	3659	1108
206 (8)	2.83	2.61	0.10	0.09	2.01	1.83	0.19	35	2234	535

^z TN = total nitrogen, ON = organic nitrogen, NO₃-N = nitrate nitrogen, NH₃-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 Number of samples are shown in parenthesis.

^x No samples.

Stations 204 and 205 more frequently and severely than the other two Stations (field-based observations). Another distinction is that Station 203 is in a grassed ditch and Station 206 has an extensive grassed buffer upstream of the flume; whereas, Stations 204 and 205 do not as much grassed buffer upstream. This may help to explain why ON remained a dominant form of N in runoff in 2010 and the average TP and TDP concentrations were similar during snowmelt and rainfall runoff at Stations 203 and 206.

Total N and ON peaks occurred on similar days throughout most of 2010 at Stations 203 and 206, with the exception of the May 28 rainfall runoff event (Figure 4.24a,d). Total N and NO₃-N peaks tended to occur on the same days at Stations 204 and 205 (Figure 4.24b,c). Total P and TDP concentrations mimicked each other throughout the year at all four stations and peaks of these parameters occurred in response to snowmelt and the rainfall runoff events that occurred between mid April and mid June (Figure 4.25). Ammonia-N and PP concentrations remained relatively stable throughout the year at all four stations (Figures 4.24 and 4.25).

Annual average concentrations of ON, TP, and TDP were higher in edge-of-field runoff compared to concentrations at the upstream and downstream stations in the Battersea Drain (Figure 4.26a-c). However, edge-of-field total flow volumes and loads are small relative to the in-stream flow volumes and loads; and therefore, it would be difficult to detect an effect of the edge-of-field runoff in the drain at this site. The TN and NO₃-N annual average concentrations were higher at both instream stations compared with edge-of-field Stations 203 and 206. The difference between instream and edge-of-field was much greater for TP compared to TN. This may reflect the differences in mobility between N and P in the soil. Nitrogen, in the form of NO₃-N, will readily leach downward through the soil profile and into the shallow groundwater; whereas, P tends to remain near the soil surface and is subject to loss in surface runoff. Ammonia-N concentrations

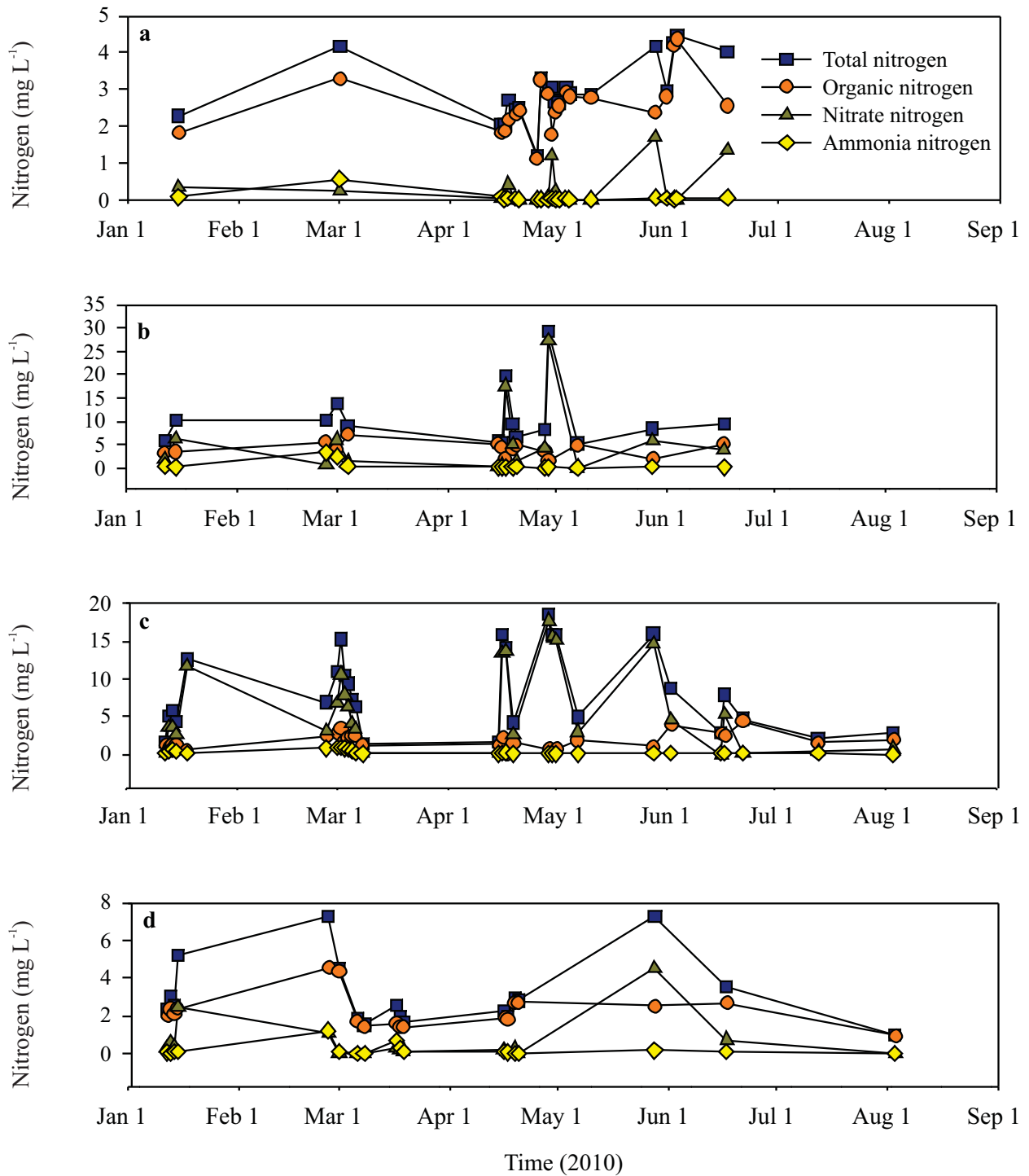


Figure 4.24. Nitrogen concentrations in surface runoff at (a) Station 203, (b) Station 204, (c) Station 205, and (d) Station 206 at the Battersea Drain Field site in 2010.

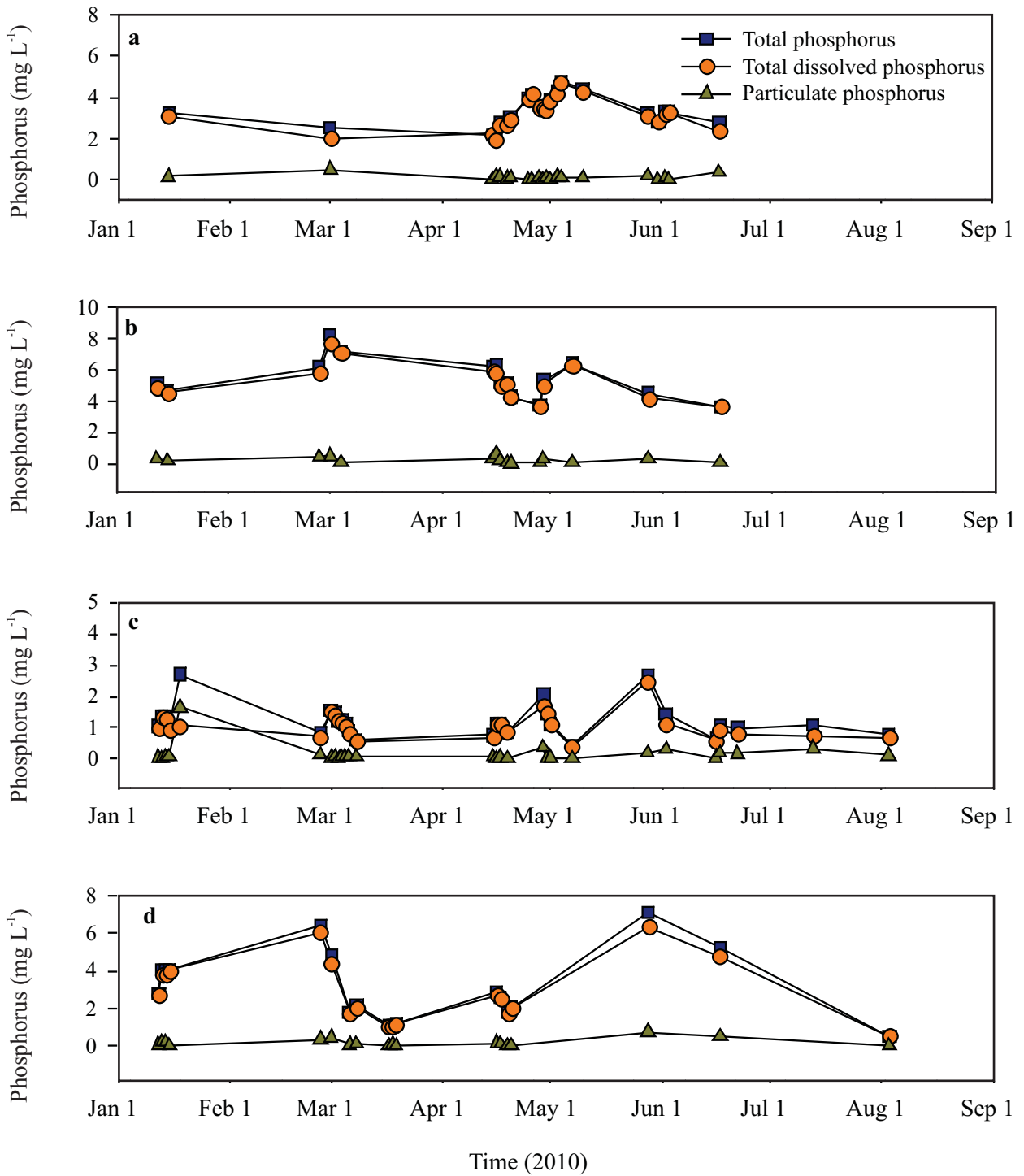


Figure 4.25. Phosphorus concentrations in surface runoff at (a) Station 203, (b) Station 204, (c) Station 205, and (d) Station 206 at the Battersea Drain Field site in 2010.

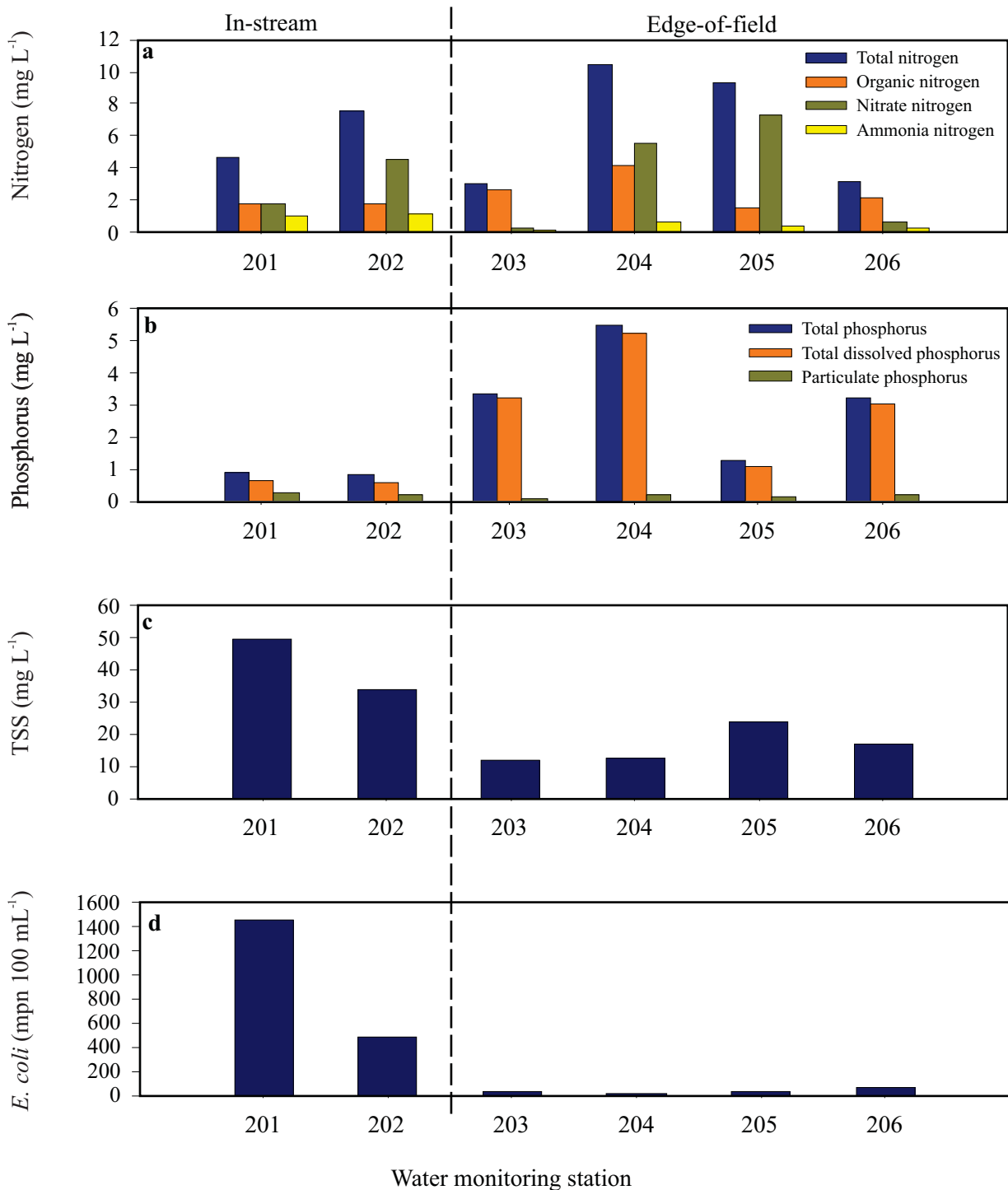


Figure 4.26. Comparison of average water quality parameters among the water monitoring stations at the Battersea Drain Field site in 2010. Station 201 is the upstream station and Station 202 is the downstream in the drain. Stations 203 to 206 are edge-of-field monitoring stations.

were higher at the instream stations compared with all four edge-of-field stations. Also, 2010 was the first year when TSS and *E. coli* annual average concentrations were greater at the instream stations compared with the edge-of-field stations.

Overall, edge-of-field parameter loads were highest in 2010 compared to loads in the previous 3 yr (Table 4.13). This was due to the two- to eight-fold larger edge-of-field flow volume in 2010 compared to 2007 to 2009. However, there were some variations among the edge-of-field stations. For example, ON, PP, and TSS loads were highest in 2008 at Stations 204, and this was due to higher concentrations in 2008.

4.6.4 Beneficial Management Practices Effects on Water Quality

At the BDF site, upstream-downstream and edge-of-field stations were used to monitor flow and water quality. A significant decrease, in the relative difference in water quality parameter concentration between the two instream stations (downstream – upstream) from pre-BMP (2007 and 2008) to post-BMP (2009 and 2010) would signify a positive effect by the BMPs and a rejection of the null hypothesis. As well, a significant decrease in average concentration from pre-BMP to post-BMP at the edge-of-field stations would signify a positive effect by the BMPs and a rejection of the null hypothesis.

Table 4.13. Load values for nutrients and total suspended solids at the edge-of-field water monitoring stations at the Battersea Drain Field site from 2007 to 2010.^z

Station	TN	ON	NO ₃ -N	NH ₃ -N	TP	TDP	PP	TSS
----- (kg) -----								
<i>2007</i>								
203	ns ^y	ns	ns	ns	ns	ns	ns	ns
204	3.51	3.28	0.11	0.10	3.21	3.00	0.21	33
205	3.29	2.19	1.01	0.06	0.72	0.35	0.36	183
206	1.55	1.39	0.06	0.08	1.03	0.92	0.11	14
Total	8.35	6.86	1.18	0.24	4.96	4.27	0.68	230
<i>2008</i>								
203	2.51	2.33	0.13	0.02	2.14	2.03	0.11	16
204	21.02	19.40	1.03	0.48	16.84	15.68	1.16	231
205	18.37	15.04	2.85	0.25	9.03	7.67	1.36	190
206	8.73	8.24	0.13	0.32	11.46	10.79	0.67	39
Total	50.63	45.01	4.14	1.07	39.47	36.17	3.30	476
<i>2009</i>								
203	1.90	1.54	0.19	0.13	1.10	1.02	0.08	15
204	14.19	7.52	6.54	0.09	6.52	6.40	0.12	13
205	26.72	16.74	8.14	1.39	19.92	16.56	3.36	3495
206	1.94	1.69	0.15	0.08	2.53	2.48	0.05	16
Total	44.75	27.49	15.02	1.69	30.07	26.46	3.61	3539
<i>2010</i>								
203	8.88	6.47	2.03	0.31	7.29	6.73	0.56	84
204	56.39	15.71	38.58	1.76	19.66	18.79	0.87	138
205	86.00	21.05	62.55	1.62	13.61	11.84	1.77	387
206	11.03	6.69	3.73	0.41	12.04	11.10	0.94	75
Total	162.30	49.92	106.89	4.10	52.6	48.46	4.14	684

^z TN = total nitrogen, ON = organic nitrogen, NO₃-N = nitrate nitrogen, NH₃-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids.

^y No runoff samples collected.

Upstream-downstream differences for TN, NO₃-N, PP, TSS, and EC were significantly larger in the post-BMP phase compared with the pre-BMP phase during high flows (Tables 4.14 and 4.15). However, the TDP difference was significantly less in the post-BMP phase during high flow. During low flows, the relative difference between upstream and downstream for ON was significantly less in the post-BMP phase. There were no significant upstream-downstream differences between the pre- and post-BMP phases when all flow events were combined.

Total N, ON, TP, and TDP concentrations were significantly less in the post-BMP phase compared with the pre-BMP phase at Stations 203 and 206 (Table 4.16). *Escherichia coli* concentrations were significantly reduced at Stations 204, 205, and 206 in the post-BMP phase. The reduction in TN, ON, TP, TDP, and *E. coli* concentrations likely was due to a combination of cessation of manure application and dilution effects at these stations by the larger runoff volumes in 2010. Particulate P concentration was also reduced in the post-BMP phase at Stations 205 and 206. Total suspended solids concentration was reduced at Station 204 in the post-BMP phase. The TSS and PP reductions were likely due to dilution effects, as the BMPs implemented at BDF site involved stopping the source of dissolved nutrients rather than erosion control. At Station 203, NH₃-N concentration was significantly higher in the post-BMP phase. Total N, NO₃-N, NH₃-N, and EC concentrations were significantly higher in the post-BMP phase at Station 204. Nitrate-N and NH₃-N concentrations were significantly higher in the post-BMP phase at Station 205.

These preliminary comparisons between pre-BMP and post-BMP phases suggest that the cessation of manure application BMP had a positive effect on nutrient concentrations at two of the edge-of-field stations and on *E. coli* concentrations at three of the edge-of-field stations. Overall, there was no significant BMP effect on instream water quality differences between the pre- and post-BMP phases.

Table 4.14. Average nitrogen and *Escherichia coli* concentrations for the upstream (Station 201) and downstream (Station 202) stations in the pre- (2007 and 2008) and post-BMP (2009 and 2010) phases, and the average differences between the two stations in the pre- and post-BMP phases.^z

Station	TN		ON		NO ₃ -N		NH ₃ -N		<i>E. coli</i>	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	----- (mg L ⁻¹) -----									
	<i>High flow (n = 62 pre, 62 post)</i>									
Downstream	0.88	3.46	0.71	1.26	0.11	1.70	0.04	0.45	1183	802
Upstream	0.97	3.16	0.84	1.25	0.06	1.39	0.05	0.45	1449	1753
<i>Difference</i> ^y	-0.09b	0.30a	-0.13	0.01	0.05b	0.31a	-0.01	0	-266	-951
	<i>Low flow (n = 13 pre, 39 post)</i>									
Downstream	12.46	10.31	1.69	1.50	10.03	7.65	0.60	1.01	22	87
Upstream	2.06	3.23	1.28	1.50	0.34	0.73	0.41	0.96	17	106
<i>Difference</i>	10.40	7.08	0.41a	0b	9.69	6.92	0.19	0.05	5	-19
	<i>All flows (n = 75 pre, 101 post)</i>									
Downstream	2.89	6.11	0.88	1.35	1.83	4.00	0.13	0.67	976	526
Upstream	1.16	3.19	0.91	1.35	0.11	1.14	0.11	0.65	1197	1117
<i>Difference</i>	1.73	2.92	-0.03	0	1.72	2.86	0.02	0.02	-221	-591

^z TN = total nitrogen, ON = organic nitrogen, NO₃-N = nitrate nitrogen, NH₃-N = ammonium nitrogen, *E. coli* = *Escherichia coli*.

^y Average differences for pre- and post-BMP phases per parameter and event type followed by letters are significantly different at $P < 0.10$.

Table 4.15. Average phosphorus concentration, total suspended solids concentration, and electrical conductivity for the upstream (Station 201) and downstream (Station 202) stations in the pre- (2007 and 2008) and post-BMP (2009 and 2010) phases, and the average differences between the two stations in the pre- and post-BMP phases.^z

Station	TP		TDP		PP		TSS		EC	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	----- (mg L ⁻¹) -----									
<i>High flow (n = 62 pre, 62 post)</i>										
Downstream	0.12	0.55	0.07	0.40	0.05	0.15	10	26	417	854
Upstream	0.15	0.56	0.06	0.42	0.09	0.14	34	24	421	816
<i>Difference^y</i>	<i>-0.03</i>	<i>0.01</i>	<i>0.01a</i>	<i>-0.02b</i>	<i>-0.04b</i>	<i>0.01a</i>	<i>-24b</i>	<i>2a</i>	<i>-4b</i>	<i>38a</i>
<i>Low flow (n = 13 pre, 39 post)</i>										
Downstream	0.26	0.52	0.06	0.35	0.20	0.16	126	24	1593	1369
Upstream	0.45	0.65	0.11	0.36	0.33	0.28	116	58	1301	1207
<i>Difference</i>	<i>-0.19</i>	<i>-0.13</i>	<i>-0.05</i>	<i>-0.01</i>	<i>-0.13</i>	<i>-0.12</i>	<i>10</i>	<i>-34</i>	<i>292</i>	<i>162</i>
<i>All flows (n = 75 pre, 101 post)</i>										
Downstream	0.15	0.54	0.07	0.38	0.08	0.15	32	25	636	1053
Upstream	0.20	0.59	0.07	0.39	0.13	0.20	49	37	580	967
<i>Difference</i>	<i>-0.05</i>	<i>-0.05</i>	<i>0</i>	<i>-0.01</i>	<i>-0.05</i>	<i>-0.05</i>	<i>-17</i>	<i>-12</i>	<i>56</i>	<i>86</i>

^z TP = total phosphorus, total dissolved phosphorus = TDP, particulate phosphorus = PP, total suspended solids = TSS, EC = electrical conductivity.

^y Average differences for pre- and post-BMP phases per parameter and event type followed by letters are significantly different at $P < 0.10$.

Table 4.16. Pre- BMP and post-BMP phase comparison of average water quality parameters for the edge-of-field monitoring stations at the Battersea Drain Field site.^z

Phase	TN	ON	NO ₃ -N	NH ₃ -N	TP	TDP	PP	TSS	<i>E. coli^y</i>	EC
	----- (mg L ⁻¹) -----								(mpn 100 mL ⁻¹)	(μS cm ⁻¹)
<i>Station 203 (n = 17 pre, 30 post)</i>										
Pre-BMP	4.26a	4.01a	0.15	0.06b	3.74a	3.50a	0.24	13.3	2624	2962
Post-BMP	3.25b	2.77b	0.32	0.12a	3.06b	2.94b	0.12	15.8	268	2119
<i>Station 204 (n = 30 pre, 27 post)</i>										
Pre-BMP	6.89b	5.92	0.79b	0.13b	5.02	4.77	0.25	34.3a	4562a	2519b
Post-BMP	10.58a	5.35	4.73a	0.39a	5.33	5.13	0.20	11.7b	424b	4016a
<i>Station 205 (n = 32 pre, 46 post)</i>										
Pre-BMP	6.75	4.15a	2.27b	0.18b	1.95	1.61	0.34a	109.0	2362a	1304
Post-BMP	7.01	2.29b	4.22a	0.41a	1.65	1.46	0.19b	82.7	640b	1250
<i>Station 206 (n = 27 pre, 28 post)</i>										
Pre-BMP	8.86a	7.97a	0.32	0.53	7.46a	7.03a	0.43a	23.4	2287a	802a
Post-BMP	4.04b	3.16b	0.54	0.27	4.59b	4.35b	0.24b	16.5	693b	479b

^z TN = total nitrogen, ON = organic nitrogen, NO₃-N = nitrate nitrogen, NH₃-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 Average BMP phase concentrations per parameter followed by letters are significantly different at $P < 0.10$.

4.7 Summary and Future Work

The second year of post-BMP monitoring was carried out at the BDF site in 2010 following the 2-yr pre-BMP phase. Barley was grown for silage in 2010. The implemented BMPs included (1) a stoppage of manure application, (2) no fertilizer N application based on a nutrient management plan, (3) irrigation management using the AIMM software, and (4) control modifications to the pivot to reduce the amount of water applied to the critical runoff areas.

In spring 2010, the irrigation pivot system was further modified so that half of the nozzles on the last span before the corner arm could be turned off to reduce the amount of water applied over the low area draining to Station 205 where irrigation runoff was still observed in 2009. The AIMM software was successfully used to determine the timing of irrigation. Irrigation started on July 12 and continued until July 25 applying a total of 98 mm in five continuous circles. The cost associated to the implementation of the BMP in 2010 was \$19,197, most of which was associated to manure hauling further away from the BMP site. This brings the grand total BMP cost to \$43,427 and 17 h of labour for the last 3 yr.

Total annual precipitation received in 2010 was 451 mm including 287 mm during the growing season (April to September), which was above the 30-yr average and the previous years of the project (2007 to 2009). Monthly average daily temperatures were below the 30-yr average between April and September.

Comparisons of the pre- and post-BMP phases indicated that $\text{NO}_3\text{-N}$ concentrations in spring agronomic soil samples were significantly reduced from the pre-BMP to post-BMP phase. Ammonia-N concentrations were significantly decreased in spring and fall post-BMP phase and there were no significant changes in STP concentrations from pre- to post-BMP.

The total volume of water measured in Battersea Drain in 2010 was similar to flow measured during the previous 3 yr with more than 90% of the flow from mid April to mid October. Low flow volumes generally occurred during the non-irrigation season from shallow groundwater discharge. Total flow volume at the edge-of-field stations in 2010 was two- to six-fold larger compared to annual runoff volumes from 2007 to 2009. The BMP successfully controlled the irrigation runoff at Station 206. However, back-up flow from Battersea Drain and drainage from adjacent south quarter section affected our ability to measure the effectiveness of the irrigation runoff control BMP at the other edge-of-field stations.

Most instream water quality parameter average concentrations, with the exception of total TSS and *E. coli*, were higher in 2010 compared with the previous 3 yr and this was attributed to the increased volume of runoff and reduced dilution from irrigation water in Battersea Drain in 2010. Edge-of-field parameter loads were highest in 2010 compared to loads in the previous 3 yr. Total dissolved P was the dominant form of P at all four edge-of-field stations in 2010, and this was consistent with the previous 3 yr. Annual average concentrations of ON, TP, and TDP were higher in edge-of-field runoff compared to concentrations at in-stream stations in the Battersea Drain. However, edge-of-field total flow volumes and loads were too small relative to the in-stream flow volumes and loads to detect an effect of the edge-of-field runoff in the drain at this site.

Comparisons of pre-BMP (2007 and 2008) and post-BMP (2009 and 2010) phases indicated that upstream-downstream differences for TDP were significantly less in the post-BMP phase compared to the pre-BMP phase during high flows. However, the differences for EC, $\text{NO}_3\text{-N}$, TN, PP, and TSS were significantly larger in the post-BMP phase. During low flows, ON differences were significantly less in the post-BMP phase. There were no significant upstream-downstream differences between the pre- and post-BMP phases when all flow events were combined.

Statistical comparison of pre- and post-BMP phases at the edge-of-field stations suggest that the cessation of manure application BMP had a positive effect on nutrient concentrations at two of the edge-of-field stations and on *E. coli* concentrations at three of the edge-of-field stations. Total N, ON, TP, and TDP concentrations were significantly less in the post-BMP phase compared with the pre-BMP phase at Stations 203 and 206.

Future work will include continuation of water flow and quality monitoring in the drain (upstream and downstream) and from the edge-of-field stations. No manure or other source of P will be added. Through soil testing and nutrient management planning, crop N requirements will be assessed on an annual base. The current nutrient management plan recommends the addition of 168 to 179 kg/ha of N for the 2011 potato crop. Detailed irrigation management using the AIMM and sprinklers valves to limit irrigation flow in critical runoff areas will be carried out in the 2011 growing season.