2 GENERAL METHODS

2.1 Introduction

This section provides a general description of study sites, experimental approach, and most methods used during the study. The methods described include those used either throughout the study, on a watershed-wide basis, or at most of the beneficial management practice (BMP) sites. Site specific details (e.g., dates, number of samples, etc.), deviations from the general methods for a given site, or site-specific methods are described in Sections 3, 4, 5, and 6.

2.2 Study Sites

Two main watersheds were selected for this study, as well as two individual field sites outside of these watersheds. The watersheds were the Indianfarm Creek (IFC) Watershed (14,145 ha) near Pincher Creek and the Whelp Creek (WHC) Sub-watershed (4595 ha) near Lacombe (Figure 2.1). The two field sites were selected northeast of Lethbridge: one field (65 ha) in the Battersea Drain Watershed and the other field (130 ha) in the Lower Little Bow River Watershed. These two field sites were under irrigation and had a history of extensive beef manure application.

Several factors were considered during the selection process of the watersheds. These included physical factors, agricultural factors, and level of cooperation by local producers. The primary physical factor considered was hydrological activity. The watersheds were required to generate runoff within the 6-yr period of the project. Travel distance to the watersheds and access within the watersheds were also considered. The watersheds had to be agriculturally intensive and diverse, with little or no non-agricultural influences on the landscape. The level of diversity required a range of livestock operations, forage production, rangeland, and annual crop production. The initial assessment of agriculture intensity and diversity also provided an indication of possible opportunities to implement and test BMPs in the watersheds. The final factor used to select watersheds was the level of cooperation from local producers.

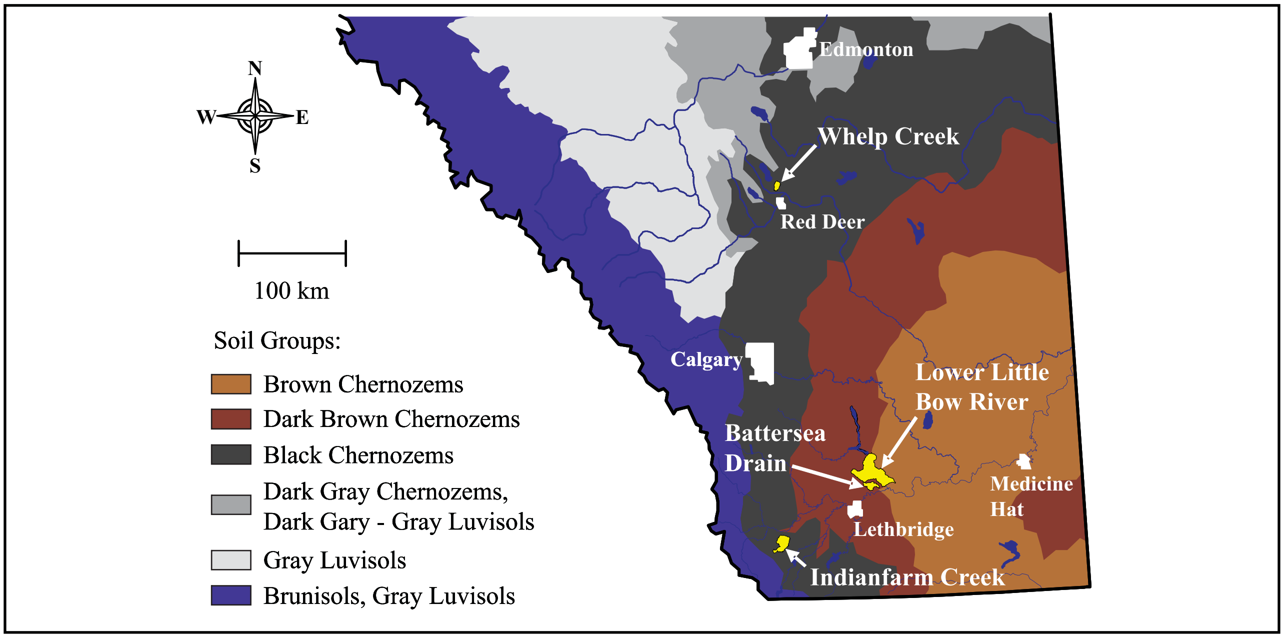

Figure 2.1. Location of the Indianfarm Creek, Whelp Creek, Battersea Drain, and Lower Little Bow River watersheds relative to the soil groups in Alberta, based on a map adapted from Alberta Agriculture, Food and Rural Development (2005a).

Based on the methodology described by Anderson et al. (1999) and Johnson and Kirtz (1998) used for the Alberta Environmentally Sustainable Agriculture Water Quality Monitoring Project (Lorenz et al. 2008), the IFC Watershed was rated as moderate agriculture intensity and the WHC Sub-watershed was rated as high agriculture intensity. Agriculture intensities were based on agriculture census of pesticide sales, fertilizer sales, and manure production data. Both watersheds have extensive crop and livestock production. More detailed information is presented in Section 3 for the IFC Watershed and in Section 4 for the WHC Sub-watershed. As well, detailed information is provided in Section 5 for the Battersea Drain Field (BDF) site and in Section 6 for the Lower Little Bow Field (LLB) site.

Within the IFC and WHC watersheds, several sites were selected to assess individual BMPs (Table 2.1 and Figure 2.2). There were seven original sites in the IFC Watershed: Impoundment (IMP), Wintering (WIN), Pasture (PST), North Manure Field (NMF), South Manure Field (SMF), Dairy Manure Field (DMF), and Reference (REF) sites. In 2010 and 2011, five additional BMP sites were included: Fencing (FEN), Dugout (DUG), Off-stream Watering (OSW), Feedlot (FLT), and Catch Basin (CAT) sites. Six BMP sites and two reference sites (REF1 and REF2) were established in the WHC Sub-watershed. The six BMP sites included the North Field (NFD), West Field (WFD), South Field (SFD), East Field (EFD), North Pasture (NPS), and South Pasture (SPS). Including the BDF and LLB sites, there was a total of 22 BMP and reference sites.

The BMP plan designed for each site involved a suite of BMPs and the sites were monitored to assess the suite of BMPs rather than individual BMPs. In this study, the BMP sites were grouped into four general management categories: (1) cattle management, (2) manure nutrient management, (3) surface-water management, and (4) irrigation management (Table 2.1). Cattle management BMPs involved infrastructure alterations, off-stream watering, windbreaks, fencing, and/or improved grazing plans. The manure nutrient management BMPs involved cropland and the implementation of modified nutrient management plans, manure application setback areas from water bodies, and/or buffer zones. In addition, irrigation BMPs were implemented at the BDF and LLB sites. A detailed description of each BMP site is presented in subsequent sections of this report.

Table 2.1. Beneficial management practice (BMP) sites and BMP plan descriptions.

			Indianfarm Creek Watershed
Impoundment	IMP[z]	C[y]	Cattle distribution tools using with fencing, off-stream watering, portable windbreak, bioengineering.
Wintering	WIN	C	Wintering site relocation, cattle distribution tools, grazing management, off-stream watering, bioengineering.
Pasture	PST	C	Corral removal, grazing management, windbreaks, off-stream watering, bioengineering.
Dairy Manure Field	DMF	N	Nutrient management plan, cessation of manure application.
North Manure Field	NMF	C	Cattle distribution tools during fall grazing.
South Manure Field	SMF[x]	N	
Reference	REF	C	Cattle distribution tools during fall grazing.
Dugout	DUG	C	Restrict access of cattle to dugouts with fencing, off-stream watering, improved cattle crossing with a bridge.
Off-stream Watering	OSW	C	Off-stream watering, restrict access of cattle to a dugout with fencing.
Feedlot	FLT	C,S	Relocation of bedding and feeding site from stream, re-direct stream flow, improve berms around dugout and catch basin.
Fencing	FEN	C	Prevent access of cattle to stream with fencing.
Catch Basin	CAT	S	Re-direct runon water away from feedlot pens.
			Whelp Creek Sub-watershed
North Field	NFD	N	Nutrient management plan, manure application setbacks.
West Field	WFD	N	Nutrient management plan, manure application setbacks, switch from fall to spring manure application.
East Field	EFD[w]	N	Nutrient management plan, manure application setbacks on a forage crop.
South Field	SFD	N	Nutrient management plan, manure application setbacks, grass buffer zone.
North Pasture	NPS	C	Bioengineering, reduce stocking density, extended pasture rest.
South Pasture	SPS	C	Rotational grazing management with new fencing and water system.
Reference 1	REF1		Non-BMP, non-manure monitoring site.
Reference 2	REF2		Non-BMP, non-manure monitoring site.
			Irrigated field sites
Battersea Drain Field	BDF	N,I	Nutrient management plan, cessation of manure application, pivot modification and irrigation management to control runoff from irrigation.
Lower Little Bow Field	LLB	N,I	Nutrient management plan, cessation of manure application, pivot modification and irrigation management to control runoff from irrigation, grass drainage channel.

[z] Beneficial management practices site abbreviations.
[y] C = cattle management BMPs involved infrastructure alterations, off-stream watering, windbreaks, fencing, and/or improved grazing plans; N = manure nutrient management BMPs on cropland involved nutrient management plans, application setbacks, and/or buffer zones; S = surface-water management; I = irrigation management BMPs.
[x] Due to various factors, a BMP plan was not implemented at the SMF.
[w] Because of circumstances, the EFD site could not be used to evaluate BMPs. However, this site was used to assess the risk of liquid manure application on a forage crop to runoff water quality. Also, the effects were examined of converting from a cereal crop to a perennial forage crop.

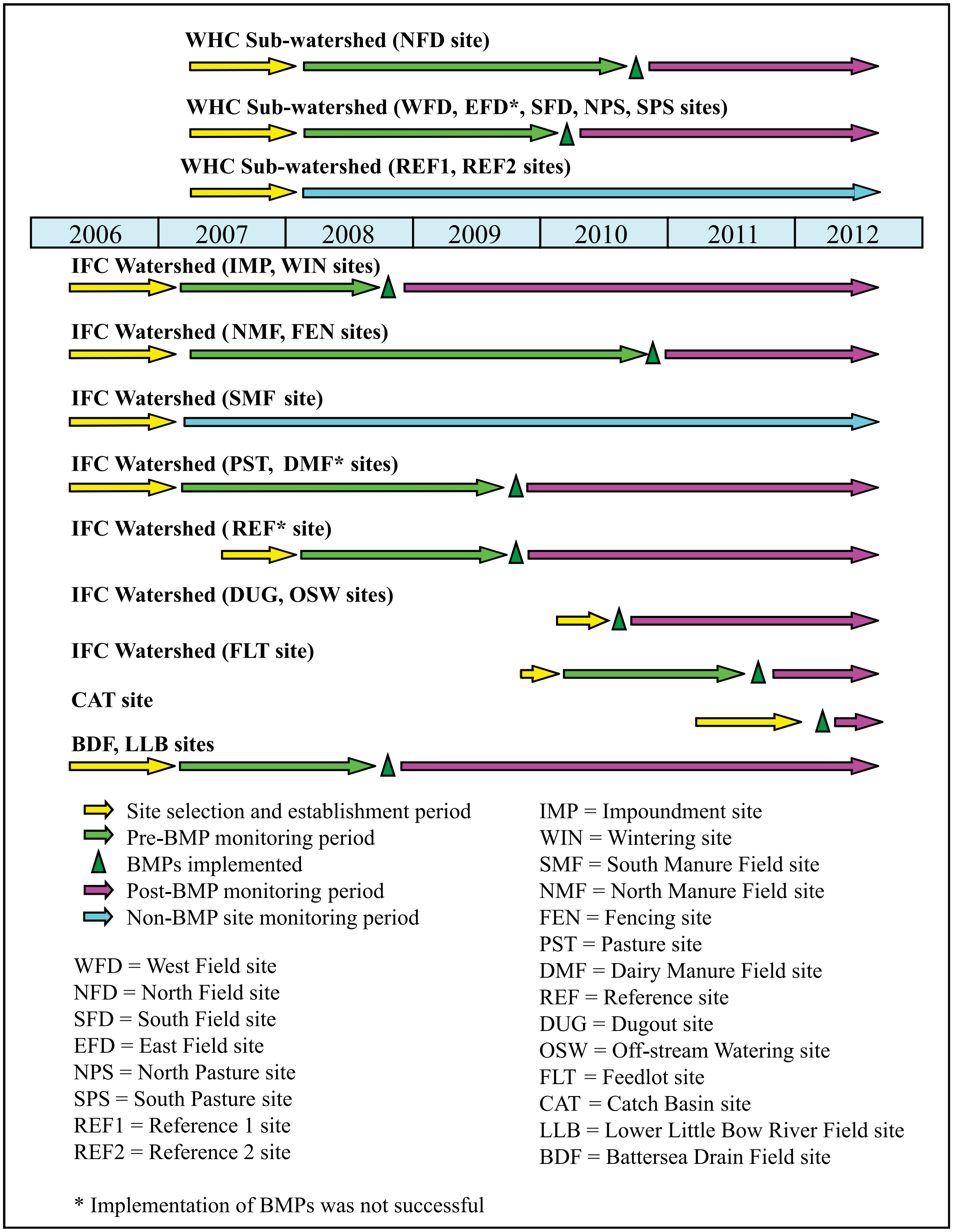

Figure 2.2. Timeline and major periods for the Whelp Creek (WHC) Sub-watershed, Indianfarm Creek (IFC) Watershed, Battersea Drain Field (BDF) site, and Lower Little Bow Field (LLB) site.

2.3 Experimental Design

There are several experimental and statistical approaches used to evaluate BMPs at field and watershed scales. An overview of these approaches is summarized in Section 1. In the current study, the before-and-after approach was adopted (Figure 2.2). The selected BMP sites were monitored for 2 to 4 yr under existing management practices. This monitoring provided the status of various indicator parameters (e.g., water quality, riparian quality) under management practices prior to BMP implementation (i.e., pre-BMP period). In cooperation with the producers, BMP plans were developed and implemented and then the sites were monitored for another 2 to 4 yr (i.e., the post-BMP period).

The main focus was on water quality; however, other indicators, such as soil, rangeland, and riparian quality, were used where applicable (Table 2.2). It was not possible to monitor water quality parameters at the FEN, DUG, OSW, FLT, and CAT sites because these sites were established late in the project. At other sites, BMPs could not be evaluated using water quality data because BMPs could not be implemented (SMF, EFD) or implemented BMPs could not be maintained (DMF, REF, FEN). Regarding water quality parameters, the monitoring method at BMP sites was either upstream and downstream monitoring or edge-of-field monitoring. For some sites, a combination of these two monitoring methods was used (Sub-section 2.6).

2.4 Weather

2.4.1 Environment Canada Data

Regional weather data were obtained from Environment Canada weather stations nearest to the study areas. These data were used for the time period before weather stations were installed in the study watersheds, and were used throughout the study period for comparison and validation of the weather data collected within the watersheds. Environment Canada data were downloaded through the Agroclimatic Information Services (ACIS) (ARD 2013) website for each year of the study. The data acquired included total daily and monthly precipitation and monthly average daily temperature. These data were provided and maintained for historical and near-real time data from meteorological stations in the province. Analysis of weather events and trends during the project were compared to the 30-yr average values (1971 to 2000) provided by Environment Canada (2013).

Pincher Creek AUT was the nearest weather station to IFC Watershed, Lacombe CDA2 was the nearest weather station to the WHC Sub-watershed, and Iron Springs and Lethbridge CDA were the nearest weather stations to BDF and LLB (Table 2.3).

2.4.2 Study Site Weather Stations

In 2008, automated weather stations were installed at the study areas to provide site specific weather data. The data collected from these weather stations were used to assess localized weather conditions throughout the study areas at a scale that otherwise might not be reflected in the regional weather data. These data were also used in the calibration process of the Soil and Water

Table 2.2. Overview of the data types collected at the beneficial management practice (BMPs) sites.

BMP site			Data types collected														
Site[z]	BMP plan developed	BMPs implemented	Agronomic management	Water quality	Water flow	Soil	Riparian quality	Rangeland quality	Rangeland production	Manure	BMP costs	Bioengineering costs	Photo points	Crop yield	Hydrology survey	Cattle and fecal pat counts	Irrigation volume and timing
Indianfarm Creek Watershed																	
IMP	✓	✓	✓	✓[y]	✓		✓				✓	✓					
NMF	✓	✓	✓	✓	✓	✓					✓			✓		✓	
PST	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓					
WIN	✓	✓	✓	✓	✓		✓				✓	✓					
SMF	✓		✓	✓	✓	✓				✓				✓			
DMF	✓	✓	✓	✓	✓	✓				✓	✓			✓			
REF	✓	✓	✓	✓	✓	✓					✓			✓			
FLT	✓	✓	✓	✓	✓			✓			✓		✓		✓		
DUG	✓	✓	✓				✓				✓		✓				
OSW	✓	✓	✓				✓				✓		✓				
CAT	✓	✓	✓								✓				✓		
FEN	✓	✓	**na**[x]								✓						
Whelp Creek Sub-Watershed																	
WFD	✓	✓	✓	✓	✓	✓				✓	✓			✓			
NFD	✓	✓	✓	✓	✓	✓				✓	✓			✓			
EFD	✓		✓	✓	✓	✓				✓	✓			✓[w]			
SFD	✓	✓	✓	✓	✓	✓				✓	✓			✓			
NPS	✓	✓	✓	✓	✓	✓			✓		✓	✓	✓				
SPS	✓	✓	✓	✓	✓	✓			✓		✓						
REF1			✓	✓	✓	✓								✓			
REF2			✓	✓	✓	✓								✓			
Irrigated field sites																	
LLB	✓	✓	✓	✓	✓	✓				✓	✓			✓			✓
BDF	✓	✓	✓	✓	✓	✓				✓	✓			✓			✓

[z] BDF = Battersea Drain Field, CAT = Catch Basin, DMF = Dairy Manure Field, DUG = Dugout, EFD = East Field, FEN = Fencing, FLT = Feedlot, IMP = Impoundment, LLB = Lower Little Bow River Field, NFD = North Field, NMF = North Manure Field, NPS = North Pasture, OSW = Off-stream Watering, PST = Pasture, REF = Reference, REF1 = Reference 1, REF2 = Reference 2, SFD = South Field, SMF = South Manure Field, SPS = South Pasture, WFD = West Field, and WIN = Wintering.

[y] Includes a one-time water sampling from several locations and depths from the impoundment lake.

[x] na = not applicable.

[w] Crop yield samples obtained by collecting square quadrant samples. Yield values were provided by cooperating producers for the other BMP sites with crops.

Table 2.3. Location of the Environment Canada weather stations used for the study sites.				
Weather station	Coordinates (^{o})	Elevation (m)	Agency	Direction and distance from study site
Pincher Creek AUT Puncher Creek CR10	49.52 N 113.98 W	1190	Environment Canada	12.5 km NW from the centre of Indianfarm Creek Watershed
Lacombe CDA2	52.45 N 113.75 W	860	Agriculture and Agri-Food Canada	7 km ENE from the centre of Whelp Creek Sub-watershed
Iron Springs	49.90 N 112.75 W	893	Alberta Agriculture and Rural Development	5.6 km W from the centre of Battersea Drain Field 16.5 km SW from the centre of Lower Little Bow Field
Lethbridge CDA	49.70 N 112.78 W	921	Agriculture and Agri-Food Canada	23.5 km SW from the centre of Battersea Drain Field 35.5 km SW from the centre of Lower Little Bow Field

Assessment Tool (SWAT) and Agricultural Policy/Environmental eXtender (APEX) models (Jedrych et al. 2013).

Four weather stations were used in the IFC Watershed, two weather stations were used in the WHC Sub-watershed, and one weather station was used at each of the two irrigated field sites (BDF and LLB). The data collected at the weather stations included air temperature, relative humidity, and precipitation. Instrumentation at each weather station consisted of a Texas Instruments Inc. tipping bucket rain gauge (Model TR-525USW; Dallas, Texas), Campbell Scientific snow adaptor (Model CS705 Precipitation Adaptor; Edmonton, Alberta), Lakewood Systems datalogger (Model CP-X; Edmonton, Alberta), NovaLynx wind screen (Model 260-953; Auburn, California), and Hobo temperature and relative humidity sensor (Hobo Pro v2, U23-002; Hobo Onset Computer, Bourne, Massachusetts). Snow adaptors were typically installed in late October of each year and removed the following March. The perimeter of each weather station was protected from livestock with an exclusion fence (Figure 2.3). The weather stations were removed at the end of the study in mid-2012. Data were collected from these stations for three full years (2009 to 2011) and only for a portion of 2008 and 2012. Data were downloaded on a monthly basis. Missing or erroneous data values were filled or replaced using data from the nearest regional weather station.

Figure 2.3. One of the weather stations (WWS1) used in the Whelp Creek Sub-watershed.

2.5 Land Use, Land Cover, Management, and BMP Costs

Three methods were used to collect land use, land cover, and management data: (1) visual survey using the AgCapture Program, (2) interviews with producers using survey forms, and (3) annual management updates from cooperating producers.

2.5.1 AgCapture

AgCapture, a land-cover information collection computer program developed by the former Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada, was used to inventory and map land-cover distribution in the IFC and WHC watersheds. The first generation (Version 1) of the AgCapture program was used in 2007, and this version had some limitations for gathering watershed specific information. After testing the AgCapture software in 2007, the program was enhanced in 2008 (Version 2AARD2008) and again in 2009 (Version 3AARD2009). The enhanced version of AgCapture utilized a more watershed specific template in which quarter sections were divided into land-use polygons; whereas, in the prior version, this could not be done (Figure 2.4). Land-use polygons were established in 2008 by manually digitizing the original parcel fabric by overlaying the quarter-section map onto satellite imagery. By isolating the polygons, the AgCapture software applied a suite of questions, which provided a more accurate view of land-use practices at the polygon level within the watershed. In 2009, the watershed boundary of the IFC Watershed was also revised. In 2007 and 2008, the watershed boundary included the outlet at Pincher Creek (Figure 2.4); whereas, in 2009 and subsequent years, water monitoring Station 1 was considered the outlet, and a small portion of the northern part of the watershed was not included (Figure 2.4). Station 1 (Sub-section 2.6) was about 1.4 km upstream from the outlet at Pincher Creek, and this resulted in the study watershed area (14,145 ha) being slightly less than the whole watershed area (14,502 ha). The year-to-year digital modification of watershed boundaries caused discrepancies in relation to the overall area of the watershed. Thus

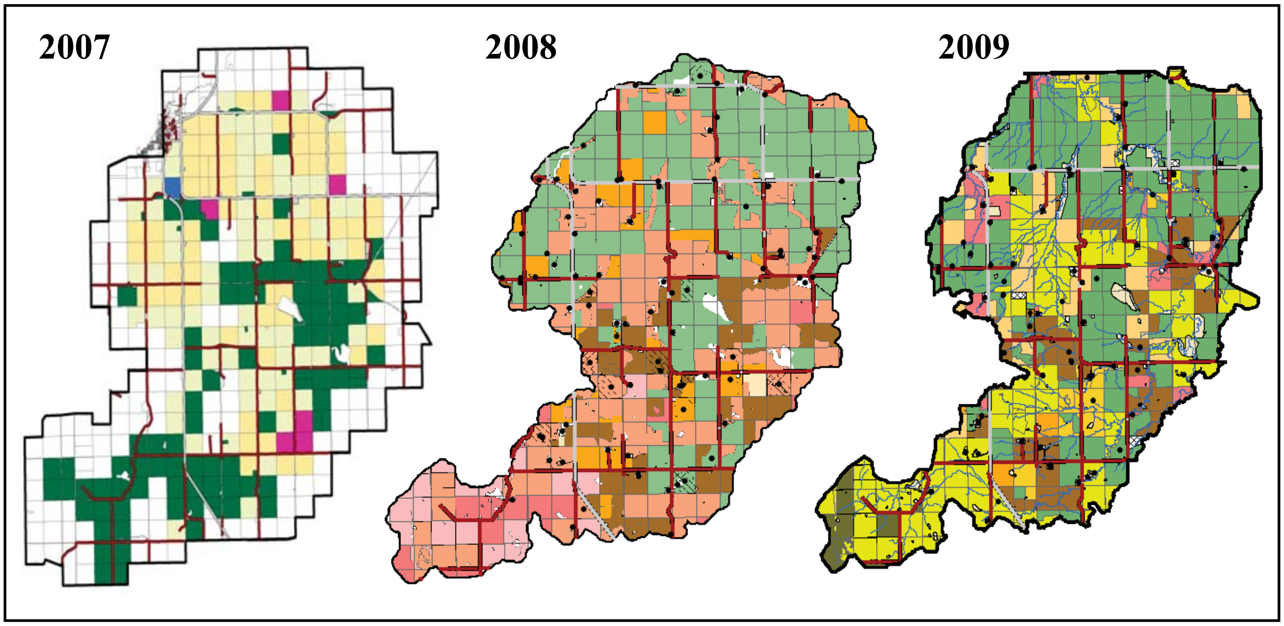

Figure 2.4. Changes to map products with modifications to AgCapture from 2007 to 2009.

the area of corresponding land-use polygons digitized within the parcel fabric and watershed boundary may have changed slightly from the previous year's polygon area. These area changes had minor effects on land-cover percentages, and therefore, comparison among years remained relevant.

The land-cover information was collected by a windshield survey while driving through the watersheds (Figure 2.5). The information was entered into AgCapture on a laptop computer. A Global Positioning System (GPS) unit was used to determine the position on the computer-generated map, and this minimized the chances of incorrectly labelling a land-cover polygon. The surveys took 2 d per watershed to complete and they were carried out in August or September each year from 2007 to 2012.

The AgCapture database was processed to create geographic information system map products, based on the 2009 templates. The mapping process populated each polygon in the watershed with the most dominant land-cover information. A colour code for each land-cover category was produced to show land-use representation throughout the watershed. The land-cover percentages and number of hectares were also calculated from the database.

2.5.2 Producers Survey

A one-time, land-use and management survey was carried out through in-person interviews in the watersheds and the two irrigated field sites at the start of the project. Comprehensive data on cropping, rotations, livestock practices, grazing management, equipment used, and nutrient management were collected. Two survey forms were used: (1) a long form for the producers with BMP evaluation sites on their property, and (2) a short form for other producers in the watershed who volunteered to participate in the survey (Appendix 1). The survey was conducted in January 2008 in the IFC Watershed, and out of about 60 producers in the watershed, 12 producers participated in the survey. The survey was conducted in February 2008 in the WHC Sub-watershed, and out of about 50 producers in the watershed, 26 producers participated in the survey.

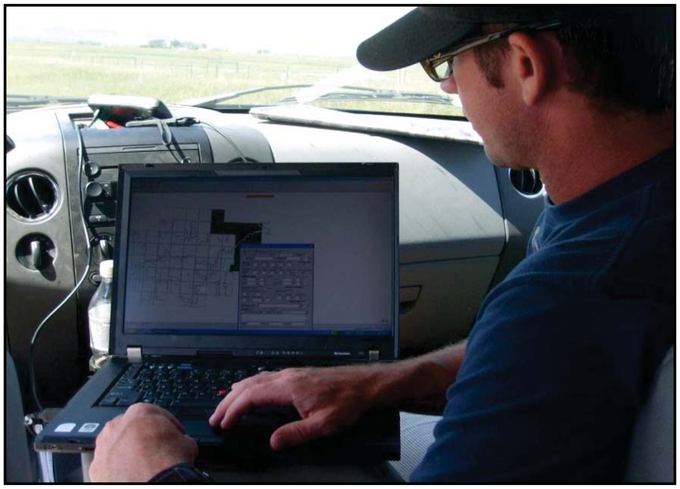

Figure 2.5. Collecting land-cover information during a windshield survey using AgCapture, a laptop computer, and GPS unit.

2.5.3 Annual Updates

Annual management updates were obtained from the cooperating producers that had BMP evaluation sites on their properties. The updates included routine management practices associated with the BMP sites. As well, management activities specific to the implemented BMPs were also recorded. Costs associated with the BMPs, including implementation costs and annual maintenance costs, were recorded. The annual update information included crop types, seeding and harvest dates, yield, fertilizer and pesticide use, manure application, number of livestock, and grazing rotations. This information was obtained by communicating with the producers and from field observations.

2.6 Water Monitoring Station Types

There were three types of monitoring stations used in this study: BMP site edge-of-field stations, BMP site instream stations, and watershed-wide instream stations (Figures 2.6, 2.7, and 2.8). The first two types were used at BMP evaluation sites, and the third type was used to assess watershed-wide water flow and quality. Some instream BMP stations were also used as watershed-wide assessment stations.

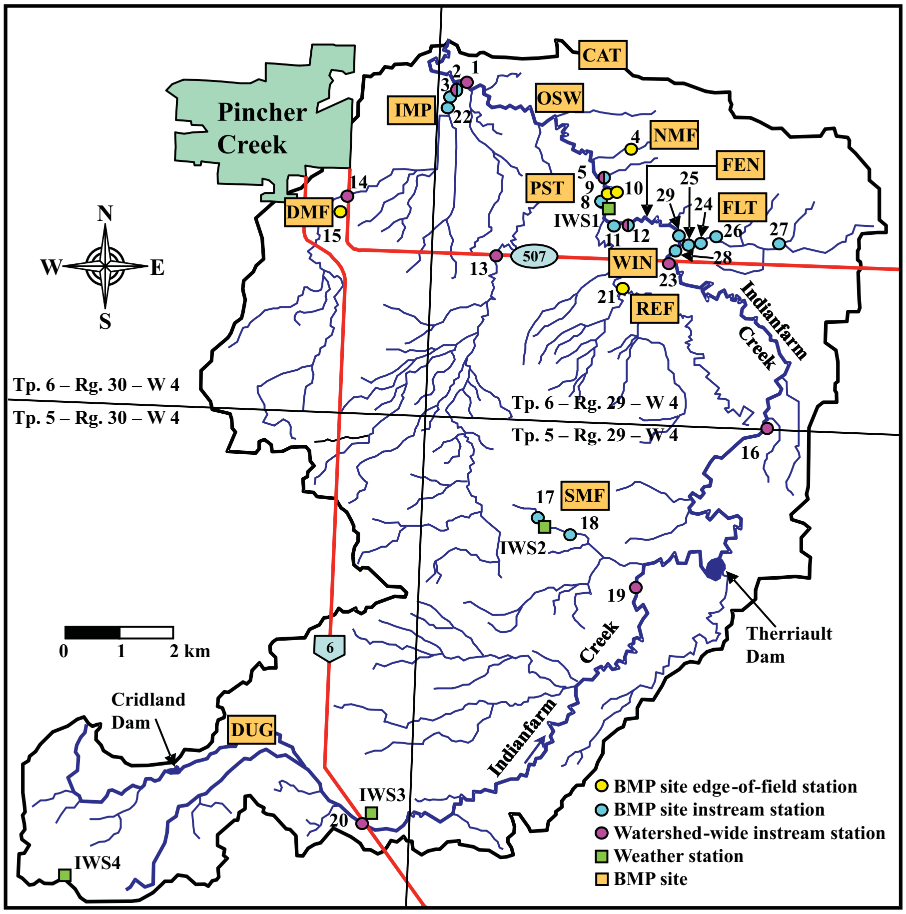

Figure 2.6. Water flow and quality monitoring stations in Indianfarm Creek Watershed.

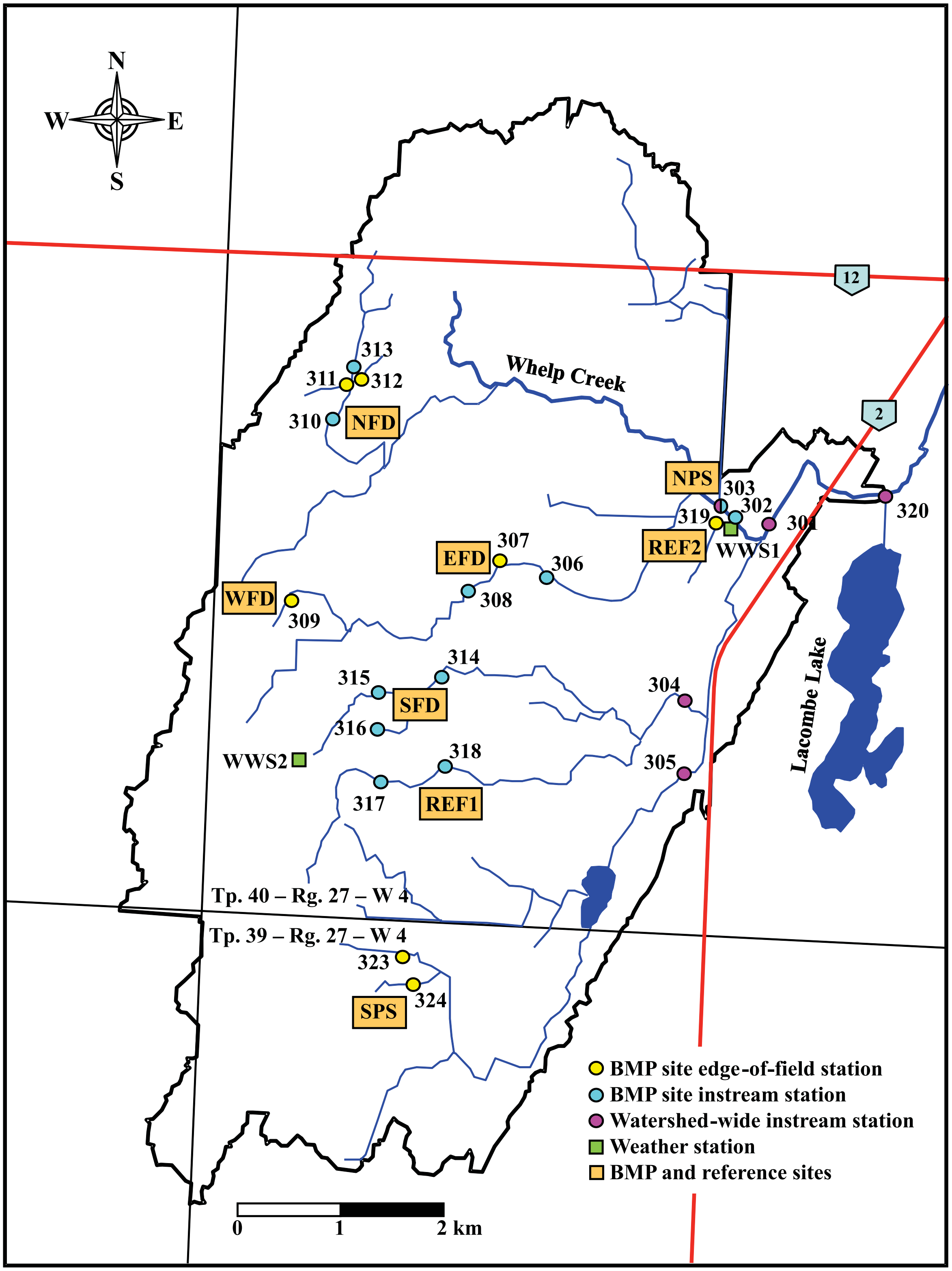

Figure 2.7. Water flow and quality monitoring stations in Whelp Creek Sub-watershed.

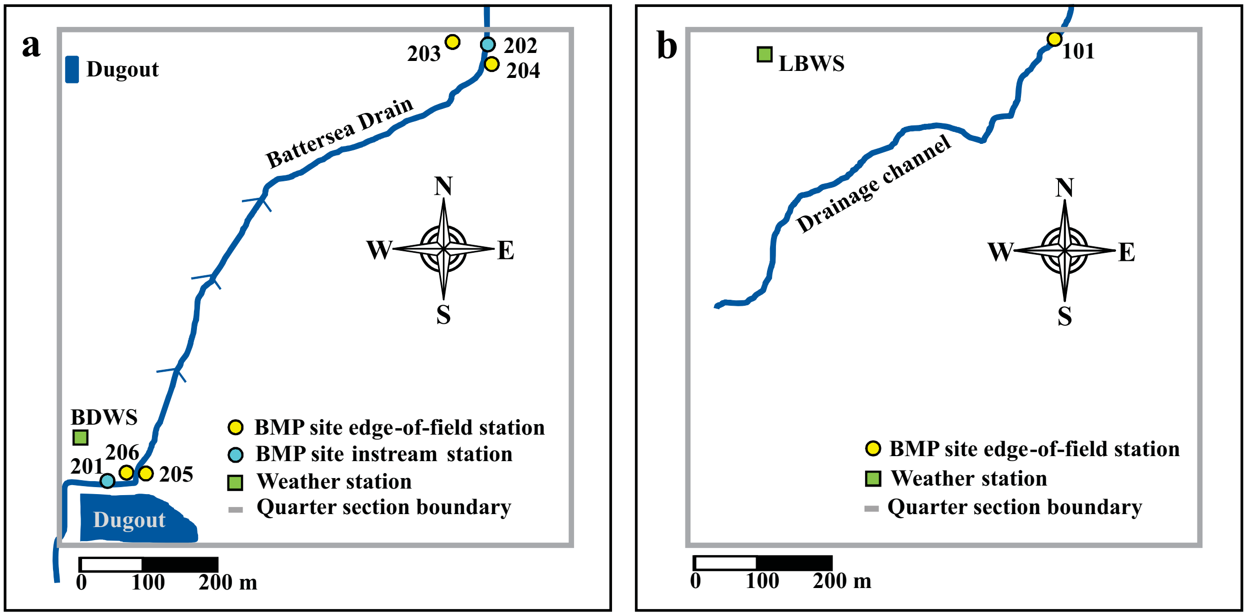

Figure 2.8. Water flow and quality monitoring stations at (a) Battersea Drain Field and (b) Lower Little Bow Field.

Edge-of-field stations were located in defined channels either near or at the edge of fields. These stations were used to measure flow and collect water samples before runoff entered a ditch, creek, or tributary. For BMP sites where runoff originated within the field, one edge-of-field station was used at or near the field exit point on the channel. For BMP sites where channelized runon occurred, more than one edge-of-field stations were used to monitor water entering and exiting the field. All edge-of-field stations for this study were instrumented with circular flumes (Samani et al. 1991) and automatic Isco water samplers (Figure 2.9 and Tables 2.4, 2.5, and 2.6).

Monitoring stations with automatic Isco water samples and other electrical equipment had wooden sheds for storage of the samplers, communications equipment, and dataloggers. These sites were powered with two solar panels and rechargeable 12-V batteries.

Instream stations at BMP sites were located in the creek or tributary and were used to monitor upstream and downstream water flow and quality of BMP evaluation sites. These instream stations were either instrumented with circular flumes, pressure transducers, acoustic doppler velocity meters, or staff gauges for flow measurement (Figure 2.10 and Tables 2.4, 2.5, and 2.6). These stations were also instrumented with automatic Isco water samplers.

The watershed-wide instream stations were distributed throughout the two watersheds and were used to monitor changes in flow and water quality as water travelled through the watersheds. These stations were instrumented with circular flumes, pressure transducers, acoustic Doppler velocity meters, or staff gauges (Tables 2.4 and 2.6) for flow measurement. Water samples were either collected by grab sampling or by automatic Isco samplers.

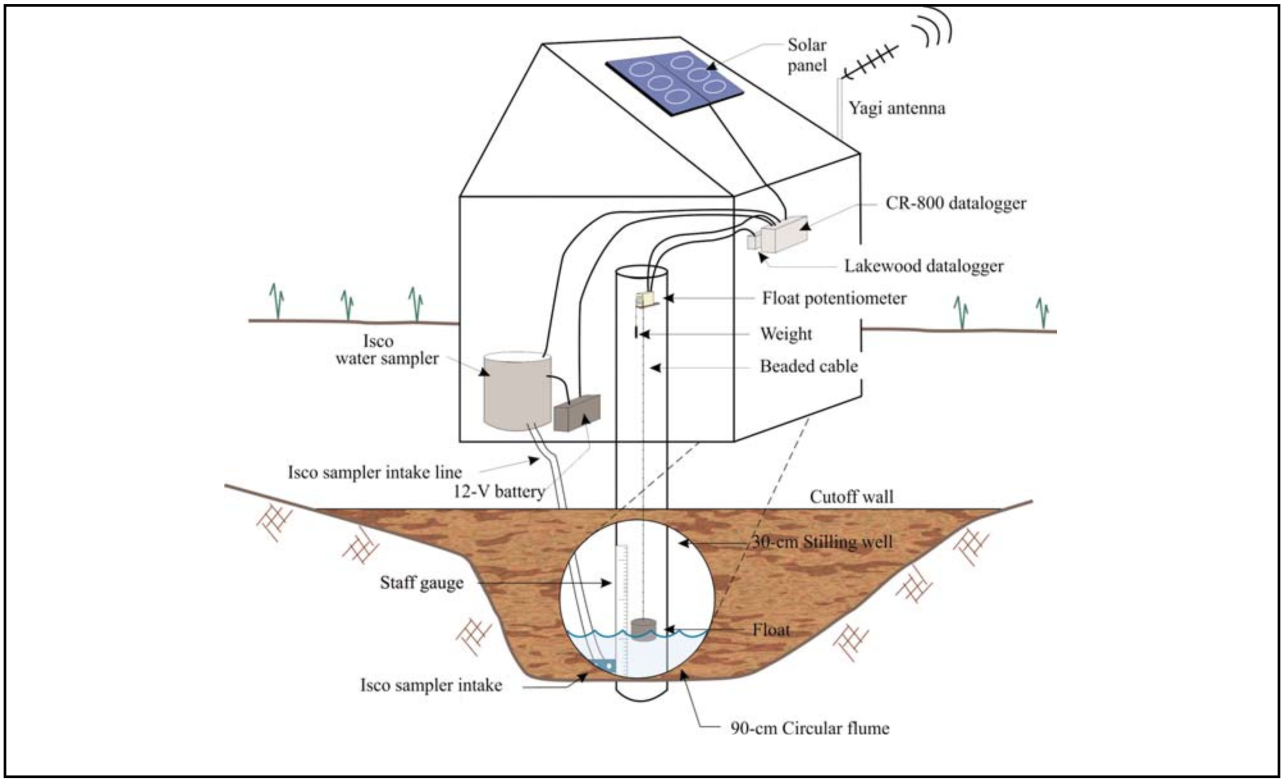

Figure 2.9. Schematic of edge-of-field monitoring station instrumentation.

2.7 Water Flow Monitoring

Each station was instrumented to monitor water stage or flow. The type of instrumentation depended on the type of flow data required (i.e., continuous or instantaneous) and the physical features of the station (Tables 2.4, 2.5, and 2.6). Most flow data, with the exception of acoustic Doppler velocity probes, were collected as water stage and converted to flow using rating curves. Float potentiometers, pressure transducers, and staff gauges were used to record water stage at the stations.

Flow measurement ceased at IFC Stations 7 and 8 in 2009 (Table 2.4), as it was determined that the margin-of-error of measurement was greater than the flow difference between Stations 5 and 8. This was also true for Stations 11 and 12 in IFC, Stations 201 and 202 at the BDF site, and Stations 302 and 303 in WHC. As a result, flow was not measured at Stations 11, 201, and 302. Flow was not measured at Station 3 because it was in the Impoundment site lake.

Table 2.4. Water monitoring station types and flow equipment used at the Indianfarm Creek Watershed.

Station	Station type	Flow measurement device	Flow calculation method
1	Watershed-wide	Level TROLL	Rating curve
2[z]	In-stream BMP and watershed-wide	Flume and float pot	0.9-m flume equation
3	Instream BMP	Staff gauge	na[y]
4	Edge-of-field	Flume and float pot	0.9-m flume formula
5	In-stream BMP and watershed-wide	Level TROLL	Rating curve
6[x]	Edge-of-field	Flume and float pot	0.9-m flume equation
7[w]	Instream BMP	Level TROLL	Rating curve
8	Instream BMP	Staff gauge	na[v]
9	Edge-of-field	Flume and float pot	0.9-m flume equation
10	Edge-of-field	Flume and float pot	0.9-m flume equation
11	Instream	Staff gauge	na[u]
12	In-stream BMP and watershed-wide	Level TROLL	Rating curve
13	Watershed-wide	Staff gauge	Rating curve
14	Watershed-wide	Staff gauge	Rating curve
15	Edge-of-field	Flume and float pot	0.9-m flume equation
16	Watershed-wide	Staff gauge/Level TROLL	Rating curve
17	Instream BMP	Flume and float pot	0.9-m flume equation
18	Instream BMP	Flume and float pot	0.9-m flume equation
19	Watershed-wide	Staff gauge	Rating curve
20	Watershed-wide	Staff gauge	Rating curve
21	Edge-of-field	Flume and float pot	0.9-m flume equation
22	Instream BMP	Staff gauge	Rating curve
23	Instream BMP	Staff gauge	Rating curve
24	Instream BMP	Level TROLL	Rating curve
25	Instream BMP	Staff gauge	Rating curve
26	Instream BMP	Staff gauge	Rating curve
27	Instream BMP	Staff gauge	Rating curve
28	Instream BMP	Staff gauge	Rating curve
29	Instream BMP	Staff gauge	Rating curve

[z] Station 2 was washed out in 2010 and not re-installed.
[y] na = not available. Flow was not determined at the Impoundment lake.
[x] Station 6 was discontinued in 2009 because of no runoff.
[w] Station 7 was discontinued in 2009 because it was no longer needed.
[v] Used flow from Station 5.
[v] Used flow from Station 12.

Table 2.5. Water monitoring station types and flow equipment used at the Lower Little Bow Field (LLB) and Battersea Drain Field (BDF).

Station	BMP site	Station type	Flow measurement device	Flow calculation method
101	LLB	Edge-of-field	Flume and float pot	0.9-m flume equation
201	BDF	Instream BMP	Staff gauge	na[z]
202	BDF	Instream BMP	Argonaut	Argonaut
203	BDF	Edge-of-field	Flume and float pot	0.29-m flume equation
204	BDF	Edge-of-field	Flume and float pot	0.44-m flume equation
205	BDF	Edge-of-field	Flume and float pot	0.29-m flume equation
206	BDF	Edge-of-field	Flume and float pot	0.29-m flume equation

[z] na = not available. Used flow from Station 202.

Table 2.6. Water monitoring station types and flow equipment used at the Whelp Creek Sub-watershed.

Station	BMP site	Station type	Flow measurement device	Flow calculation method
301		Watershed-wide	Argonaut	Argonaut
302[z]	NPS	Instream BMP	Staff gauge	Rating curve
303	NPS	Instream BMP and watershed-wide	Level TROLL	Rating curve
304		Watershed-wide	Level TROLL[y]	Rating curve
305		Watershed-wide	Level TROLL[y]	Rating curve
306	EFD	Instream BMP	Flume and float pot	Rating curve
307	EFD	Edge-of-field	Flume and float pot	0.9-m flume equation
308	EFD	Instream BMP	Flume and float pot	0.9-m flume equation
309	WFD	Edge-of-field	Flume and float pot	0.9-m flume equation
310	NFD	Instream BMP	Flume and float pot	0.9-m flume equation
311	NFD	Edge-of-field	Flume and float pot	0.9-m flume equation
312[x]	NFD	Edge-of-field	Flume and float pot	0.9-m flume equation
313	NFD	Instream BMP	Flume and float pot	0.9-m flume equation
314	SFD	Instream BMP	Flume and float pot	0.9-m flume equation
315	SFD	Instream BMP	Flume and float pot	0.9-m flume equation
316	SFD	Instream BMP	Flume and float pot	0.9-m flume equation
317	REF1	Instream BMP	Flume and float pot	0.9-m flume equation
318	REF1	Instream BMP	Flume and float pot	0.9-m flume equation
319	REF2	Edge-of-field	Flume and float pot	0.9-m flume equation
320		Watershed-wide	Staff gauge	Rating curve
323	SPS	Edge-of-field	na[w]	na
324	SPS	Edge-of-field	Flume and float pot	0.9-m flume equation

[z] Station 302 flow measurement was discontinued in 2009.
[y] Flumes in 2008 to 2009, washed out in 2010 and replaced with Level TROLLs.
[x] Station 312 discontinued in 2009.
[w] na = not available. Station 323 discontinued in 2009 and was never instrumented.

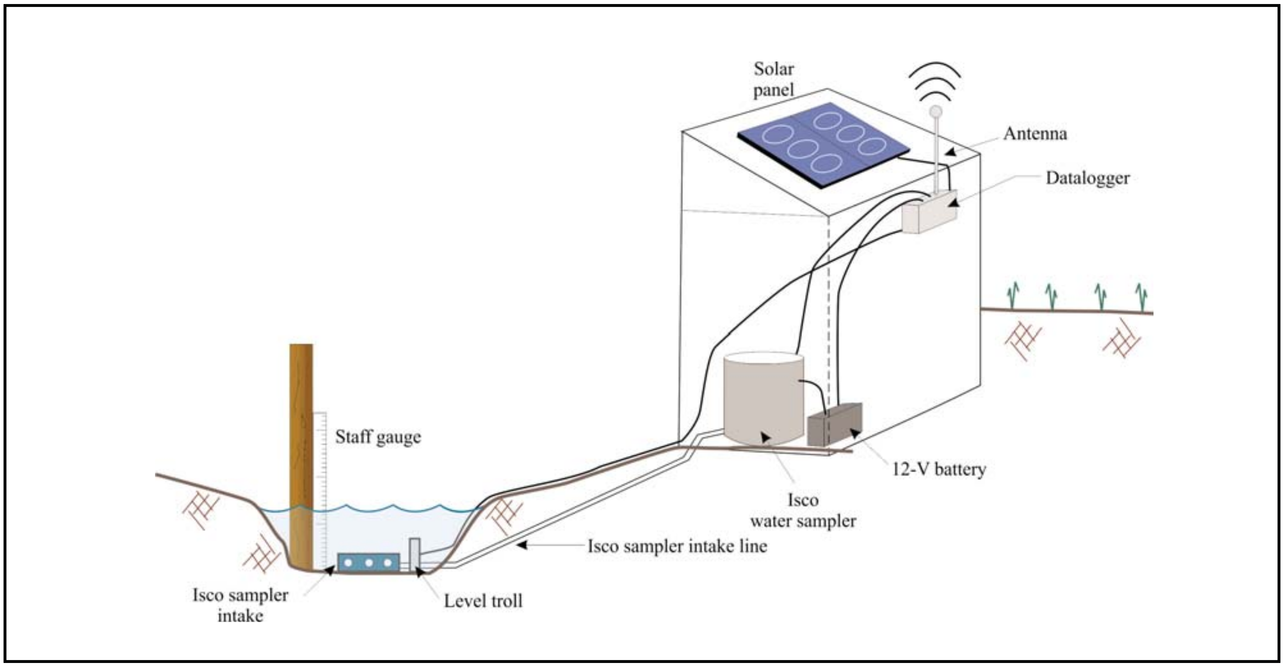

Figure 2.10. Schematic of instream monitoring station instrumentation.

2.7.1 Circular Flumes and Float Potentiometers

Three sizes of flumes were used during this study. The largest flumes were used in IFC, WHC, and LLB, and four smaller flumes were used at BDF. The largest flumes consisted of a 0.273-m internal diameter (ID) high-density polyethylene (HDPE), singled walled, straight pipe installed vertically inside a 0.9-m ID HDPE horizontal pipe (Figures 2.11 and 2.12). The horizontal pipe was doubled walled with an outer corrugated wall. The lengths of the horizontal and vertical pipes were generally 1.82 m and 2.1 m, respectively. One exception was for the LLB site flume, which had a 3-m long horizontal pipe. The vertical pipe was 0.78 m from the inlet of the flume. One vertical row of 10, 8-mm diameter holes, spaced at 10-mm intervals, was drilled at the base of the vertical pipe and the holes faced the flume inlet. Smaller versions of the circular flume made of PVC pipe were used at the BDF site (0.29-m internal diameter at Stations 203, 205, and 206 and 0.44-m internal diameter at Station 204) (Figure 2.13).

The installation of the flumes was site-specific. For example, Stations 6 and 9 had the last 5 m of the approach channel to the flume re-shaped and reinforced with erosion control matting since the disturbance caused by installation could have increased soil erosion and affected water quality. Many of the stations had plywood-reinforced earthen berms constructed to direct flow towards the inlet of the circular flume (Figure 2.14). The flumes were installed with a 1% slope, and the slope of the flumes was checked periodically.

Each flume was equipped with a float and a potentiometer (Model FS-15A Float sensor; Lakewood Systems, Inc., Edmonton, Alberta) placed within the vertical pipe to measure water stage (Figures 2.12 and 2.15a). Each potentiometer was connected to a datalogger, which recorded water stage every 15 min. When the sites were instrumented in 2007, RomComm dataloggers (ROM Communication Inc., Kelowna, British Columbia) (Figure 2.16a) were used to transmit data via cellular channels to the RomComm server, where the data were available for downloading or viewing in real-time. The LLB site used satellite transmission because of the lack of cellular coverage at the site.

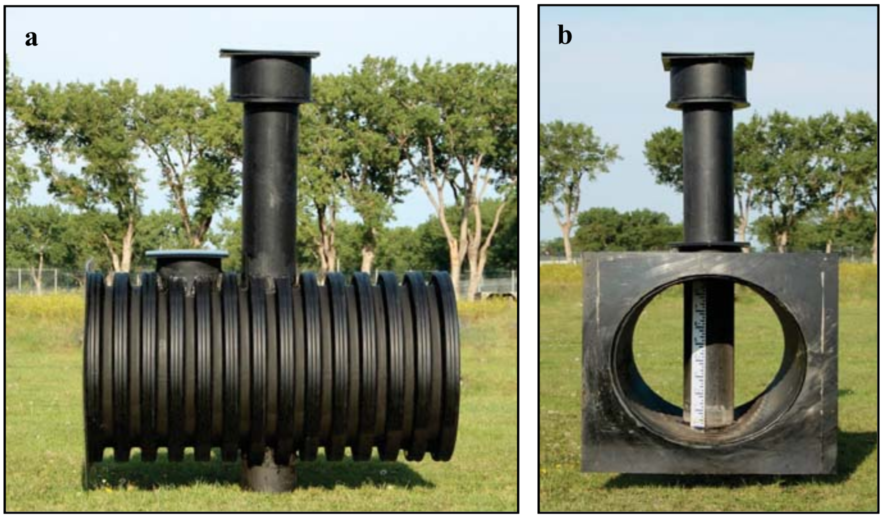

Figure 2.11. Side and front profile views of a 0.9-m diameter circular flume.

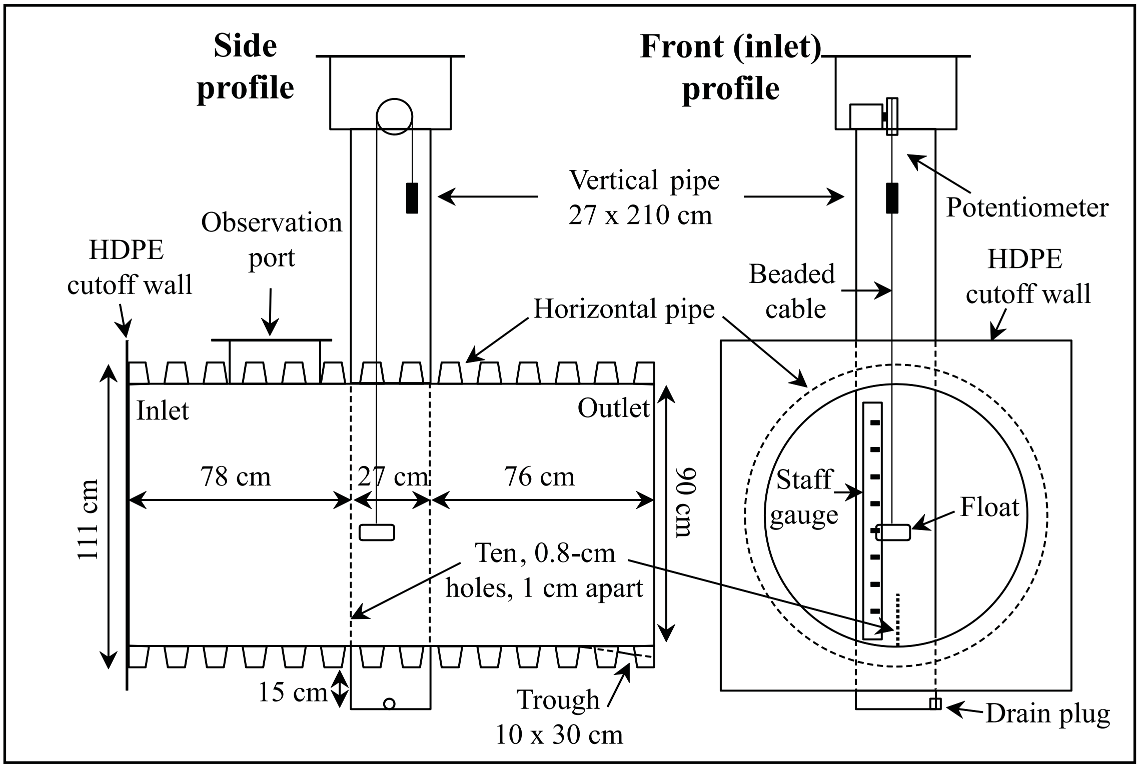

Figure 2.12 Schematic diagrams of a 0.9-m diameter circular flume.

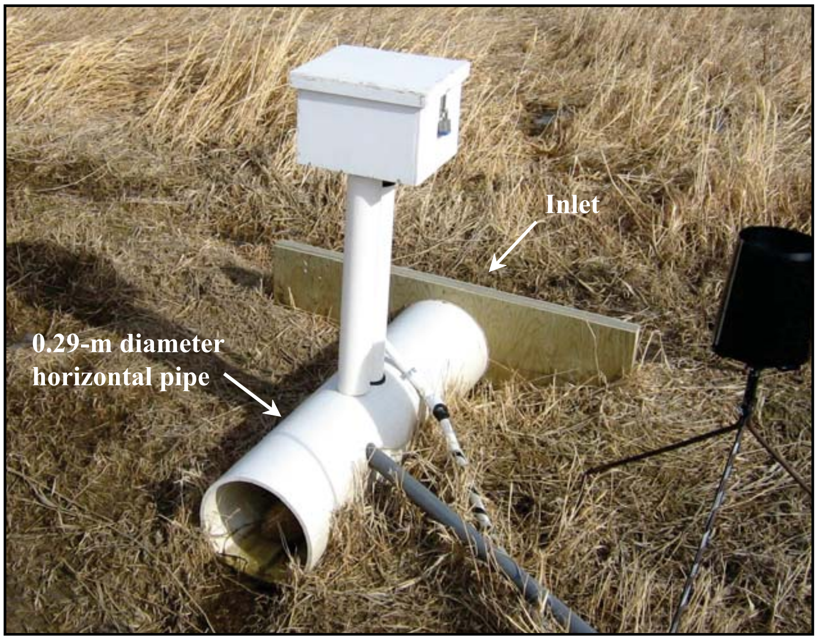

Figure 2.13. Circular flume, with a 0.29-m horizontal pipe, used at the Battersea Drain Field Station 205 (March 14, 2009).

Figure 2.14. Installation of plywood-reinforced berm and flume at Station 17.

A second float potentiometer (Figure 2.15a) and Lakewood datalogger (Model CP-X; Lakewood Systems Ltd., Edmonton, Alberta) (Figure 2.15b) were installed for backup collection of stage data. Staff gauges were mounted on the exterior of the vertical column for manual stage measurements during site visits (Figure 2.11b).

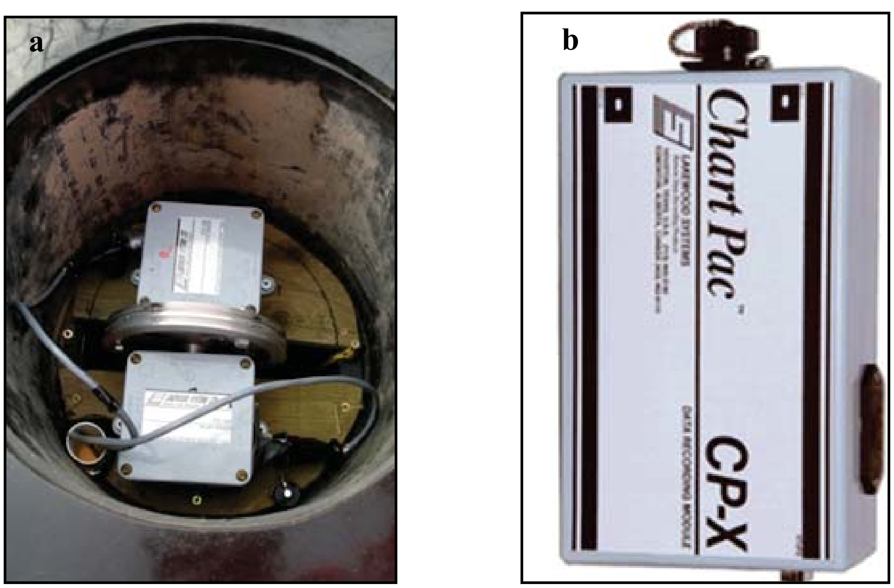

Figure 2.15. Water stage in the circular flumes was recorded using (a) two float potentiometers, with one connected to a (b) Lakewood datalogger used as a backup

Because of technical difficulties, all the RomComm systems were replaced with CR800 dataloggers (Campbell Scientific, Edmonton, Alberta) and radio communication systems at the BDF site in 2008 and at the IFC and WHC watersheds in 2009 (Figure 2.16b). The CR800 dataloggers were connected to the radio communication systems (Figure 2.16b,c), which transmitted the data to a master computer. A custom-designed computer program (Watershed Master, designed by Genivar, Lethbridge, Alberta) was used to store the data in Microsoft Access and allowed remote access through an internet connection. Nano 920SL radio systems (Microhard Systems Inc., Calgary, Alberta) were used at the IFC and WHC sites and a XTend-PKG radio system (Digi, Minnetonka, Minnesota) were used at the BDF site. Because of geographic limitations of the radio systems, the RomComm system was used at the LLB site for the duration of the study.

Prior to water stage data being converted to flows, values were corrected for the offset or the zero value of the flume. The flumes were calibrated using the Water Ware software program developed by Samani et al. (1991). The resulting calibrations for the 0.9-m circular flumes were plotted in TableCurve 2D, version 3 (Jandel Scientific Software 1994) to fit an appropriate power curve to the data (Little et al. 2006, 2007). Once a curve was selected and applied to the stage values, a correction factor was applied to account for the slope of the flume and for any inactive stage in the flume. Flows in the circular flumes were calculated using the following power functions:

0.9-m diameter circular flume
$y = 0.0702\ x^{2.093}$ Equation 2.1

0.29-m circular flume
$y = 0.04148\ x^{2.1297}$ Equation 2.2

0.44-m circular flume
$y = 0.0333\ x^{2.1994}$ Equation 2.3

Where:
y = flow (L s^{-1})
x = stage (cm)

2.7.2 Argonaut

The outlet of the WHC Sub-watershed (Station 301) and the downstream Station 202 at the BDF site were each instrumented with an Argonaut SW (SonTek/YSI, San Diego, California) (Figure 2.17). The Argonauts used acoustic Doppler technology to measure and calculate water height and velocity. The units were installed in pre-existing road culverts and were programmed with the cross-sectional information of the culverts. Flow was calculated and recorded every 15 min. Although able to store data internally, the Argonauts were connected to external dataloggers for transmission and real-time viewing of the data.

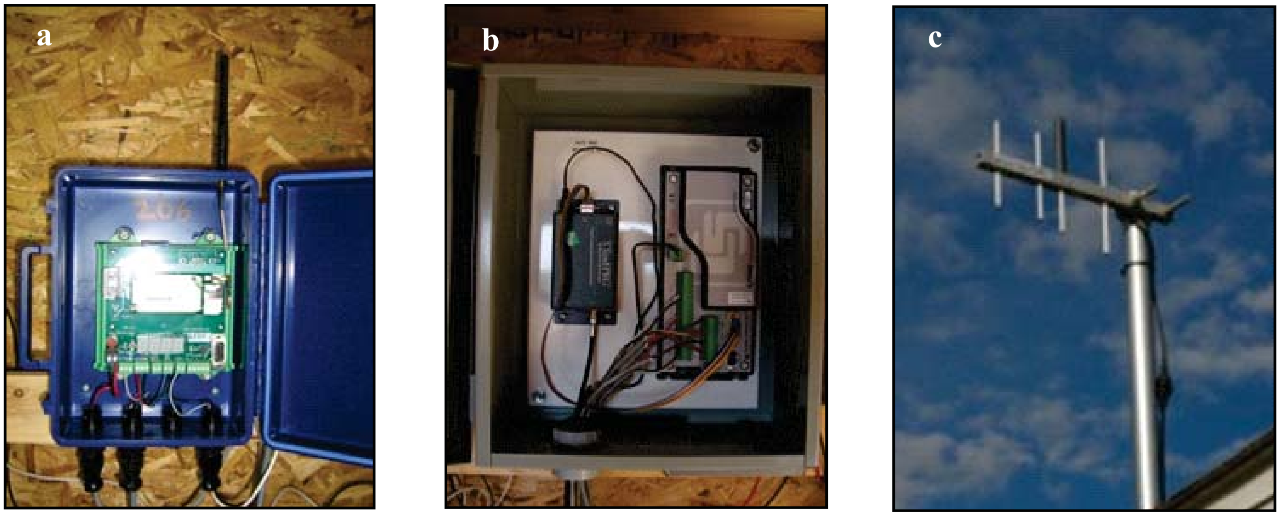

Figure 2.16. Data recording and transmission equipment: (a) RomComm datalogger, (b) CR800 datalogger with radio on left-hand side of box, and (c) radio antennae on the shed at Station 5 in Indianfarm Creek Watershed.

2.7.3 Level TROLL

Water stage at some stations was measured using Level TROLL 700 pressure transducers (Figure 2.18). The Level TROLL® 700 (In-Situ Inc., Fort Collins, Colorado) measured water pressure and converted the pressure to a depth of water. The Level TROLLs were programmed to record water stage every 15 min, and although they stored the data internally, they were connected to an external datalogger for transmission and real-time viewing of the data.

Figure 2.17. Argonaut SW acoustic Doppler velocity probe used for flow measurement at Station 301 in Whelp Creek Sub-watershed and at Station 202 at the Battersea Drain Field.

Figure 2.18. Level TROLL 700 pressure transducer used for water stage measurement at some monitoring stations in the Indianfarm and Whelp Creek watersheds.

2.7.4 Staff Gauges

Every station was instrumented with a staff gauge. Staff gauges were mounted near the edge or in the middle of the stream (Figure 2.19) for visual water stage measurement during water sampling or other site visits. These readings were used for calibration of equipment, validation of data, and calculation of instantaneous flows where no continuous flow measurement equipment was present

2.7.5 Flow Metering

For those stations equipped with staff gauges and Level TROLLs (Tables 2.4, 2.5, and 2.6), flow metering was done to develop rating curves, which were used to determine flow (L s^{-1}) from the water stage measurements. Flow metering at these stations was completed using (1) a StreamPro acoustic Doppler current profiler (Teledyne RD Instruments, Poway, California), (2) a FlowTacker acoustic Doppler velocity meter (Teledyne RD Instruments, Poway, California), or (3) a Swoffer current velocity meter (Swoffer Instruments Inc., Seattle, Washington) (Figure 2.20). The StreamPro was used during high flows when entering the water for flow metering was unsafe and the FlowTracker and Swoffer were used during normal or low flows (Figure 2.21).

Figure 2.19. Staff gauge attached to the bridge at Station 23 in the Indianfarm Creek Watershed.

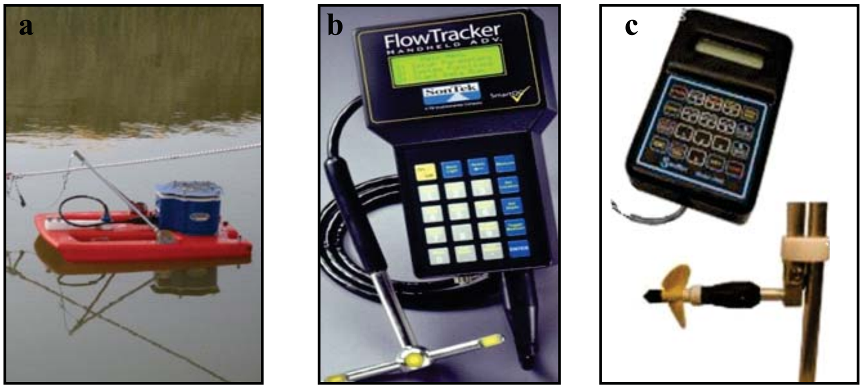

Figure 2.20. Equipment used for flow metering: (a) StreamPro, (b) FlowTracker, and (c) Swoffer velocity meters.

Figure 2.21. Flow metering using (a) a StreamPro with rope system and (b) wading instream with a FlowTracker.

Power curves (Equation 2.4) were fitted to the flow-metering data to generate a rating curve for each site. Curves were updated each year with the addition of the new flow-metering data. Flow metering was carried out at different stage heights for curve building and at regular intervals for validation of calculated data.

$$y = ax^b \qquad \text{Equation 2.4}$$

where:
y = stage (cm)
x = flow (L s^{-1})
a and b = coefficients

2.7.6 Flow Calculations and Categories

The flow calculations were carried out using Microsoft® Excel 2010®, with validation of water stage against manual staff gauge readings and offsets applied as needed. An offset is the difference between the recorded value and the real value and was usually adjusted for in the field programming of the flow measurement devices (e.g., Level TROLLs, dataloggers). Adjustments were also made to the data to account for pooled water (inactive stage) in flumes or missed flow that went around or under the flumes. Flow was expressed in cubic metres per second ($m^3\ s^{-1}$) and annual flow was expressed in cubic metres per year ($m^3\ yr^{-1}$).

Flows were categorized into runoff types based on the hydrological activity on the landscape. The main runoff types used at most sites were snowmelt, rainfall, and base flow. An irrigation runoff category was also used at the BDF and LLB sites. Base flow did not occur at the edge-of-field sites, and was only used as a category for creek and tributary instream sites and at the BDF instream sites. Flow was classified as base flow when there was not active runoff from the landscape. At times it was difficult to classify the runoff types particularly between the snowmelt period and spring rains. For example, in late April 2010 snow fell and accumulated on the ground. However, at this time, the ground was thawed and temperatures were generally above zero. Due to the thawed soil and quick snowmelt, runoff was classified as rainfall. In the IFC Watershed, water was often released from Therriault Dam in the fall. Flow in IFC caused by these dam releases was classified as base flow. At the BDF and LLB sites, runoff was occasionally generated when irrigation and rainfall occurred at the same time. When runoff events included irrigation and rainfall, those with less than 25 mm rainfall were classified as irrigation events and those with greater than 25 mm rainfall were classified as rainfall events.

2.8 Water Quality Monitoring

2.8.1 Automated Sampling

All edge-of-field BMP stations and nearly all in-stream BMP stations were equipped with either a Model 3700 or Model 6712 Isco automated water sampler (Teledyne Isco, Lincoln, Nebraska; Figure 2.22). The exceptions were Station 3 at the Impoundment lake, the Feedlot site, and Stations 302, 303, 304, and 305 in WHC (Tables 2.6, 2.7, and 2.8). Water samples at these BMP stations were grab sampled. The Isco intake lines were 38 mm in diameter and placed in a trough at the bottom of the flumes (Figure 2.23) or in the middle of the creek or tributary channel. The troughs were at the exit of the flumes and the opening of the intake lines pointed in the direction of flow. When located directly in-channel, the intake lines were fixed in position above the creek bottom and below an estimated low-flow height. This prevented bottom sediment from being sampled and still enabled water sampling in relatively low flows.

The edge-of-field flumes and float potentiometers automatically triggered the Isco samplers during flow events. The program on the master computer (i.e., Watershed Master) had predetermined stage trigger values, and when runoff began to flow through the flumes and raised the float above the trigger values, signals were sent to the Isco samplers to activate the sampling sequence (Figure 2.24). The signal was sent by cellular phone network (RomComm datalogger) or by radio (Campbell Scientific datalogger). The Isco samplers then sampled a 75-mL volume every 15 min for 24 h or until the runoff stopped, whichever occurred first. Each 15-min sample was added to a 10-L container, which was lined with a clean plastic bag, to create a composite sample. The RomComm server or Watershed Master software also sent email or pager notification to staff with information of when and what stations were sampling. The composite samples were then retrieved and subsamples obtained for laboratory analysis. The time recorded on the samples was the time of sample collection from the Isco sampler and not the time the sampling started. Remaining water sample, if any, was discarded, and a new, clean plastic bag was placed into the composite sample container. The Isco data were downloaded and the samplers reset for the next runoff event.

Figure 2.22. Model 6712 Isco water sampler for automated collection of water samples.

Figure 2.23. Isco intake line in the trough at bottom of a circular flume.

Automatic, simultaneous sampling by Iscos was required at BMP sites that had edge-of-field and instream stations in the IFC Watershed and at the BDF site (Tables 2.7 and 2.8). Using the communication system, a master-slave configuration was designed with the master stations (i.e., edge-of-field stations) programmed with water stage trigger values. When runoff exceeded the trigger value at an edge-of-field master station, the master station sent a signal to its Isco sampler as well as to the slave (i.e., associated instream station or upstream edge-of-field station) Isco samplers.

Although originally planned, a master-slave configuration did not work in WHC because of the lack of flow connectivity among sites. Instead, sites were sampled together based on their flow connectivity and field conditions at the time of sampling (Table 2.9).

A few non-BMP monitoring stations also had Isco samplers. These included Station 1 (IFC outlet) and Station 301 (WHC outlet) (Tables 2.7 and 2.9). The Isco samplers at these stations were programmed to sample 75 mL of water every 15 min for 24 h prior to watershed-wide sample collection. These data from composite Isco water samples were used for modelling purposes and to compare Isco-sample and grab-sample results.

2.8.2 Grab Sampling

To obtain a comprehensive look at the watersheds, watershed-wide assessment stations were located along the mainstems and tributaries in the IFC and WHC watersheds. These stations were grab sampled twice a week during major runoff events, once a week as the flows began to diminish, and once every 2 wk during base flow. In addition, the outlet stations in IFC and WHC were grab sampled on days when runoff events occurred. Grab samples were also taken at the instream stations at BDF once every 2 wk during the irrigation season (May to October) and monthly during the rest of the year for comparison of irrigation water to natural drainage.

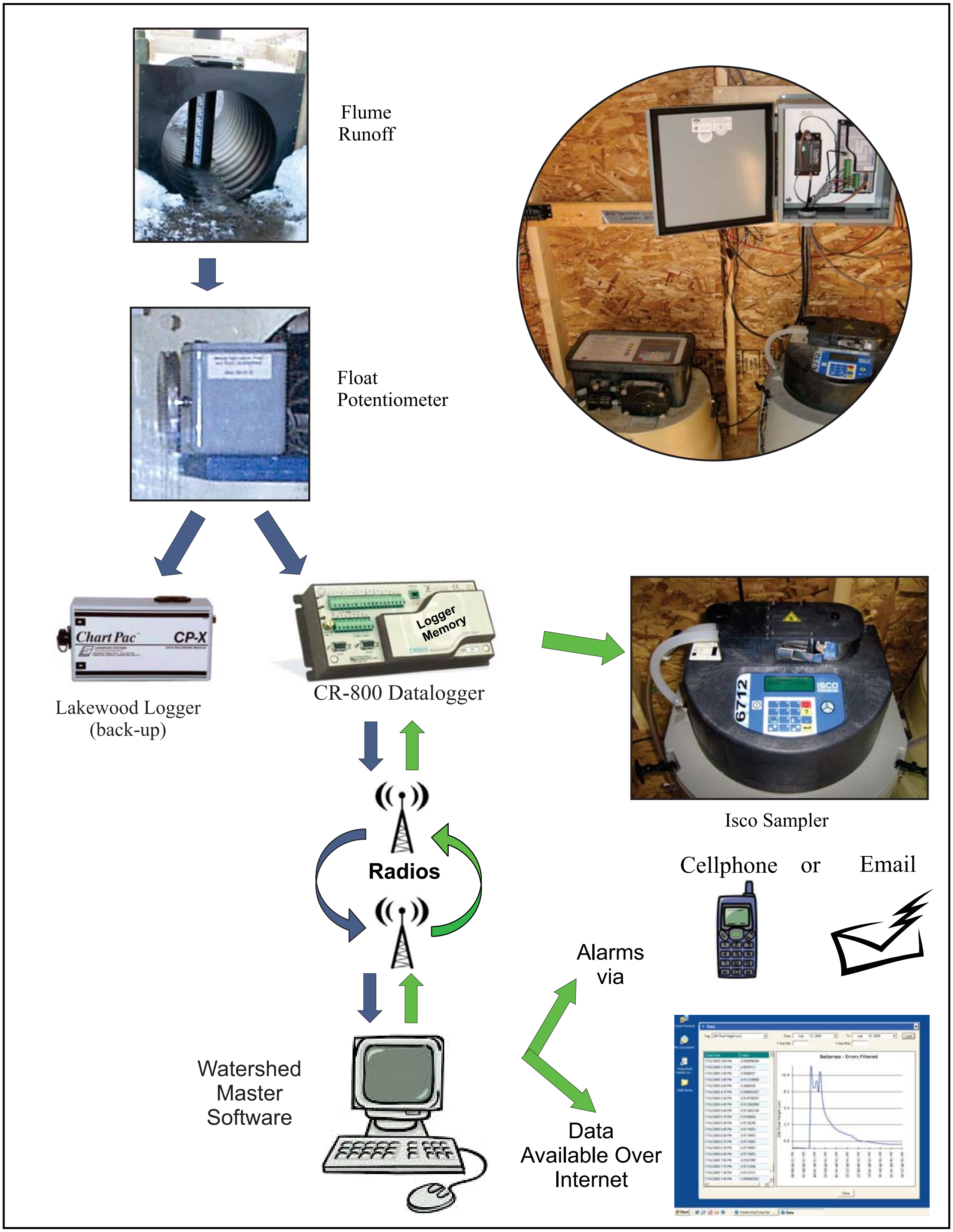

Figure 2.24. Schematic diagram of runoff event communication.

Table 2.7. Water monitoring stations in the Indianfarm Watershed (IFC).

Station	BMP site[z]	Water sampling description	Location
1		Isco and grab	Watershed outlet
2[y]		Isco, independent	Downstream of IMP site dam outlet
3	IMP	Grab	Near IMP lake outlet
4	NMF	Isco, independent	Edge-of-field
5	PST	Isco, slave to Station 9	Downstream of PST site, instream
6[x]	PST	Isco, slave to Station 9	Edge-of-field
7[w]	PST	Isco, slave to Station 9	IFC mainsteam, instream
8	PST	Isco, slave to Station 9	Upstream of PST site, instream
9	PST	Isco, master to 5, 8, 10, 11, 12	Downstream of PST coral, edge-of-field
10	PST	Isco, slave to Station 9	Upstream of PST coral, edge-of-field
11	WIN	Isco, slave to Station 9	Downstream of WIN site, instream
12	WIN	Isco, slave to Station 9	Upstream of WIN site, instream
13		Grab	IFC tributary, instream
14		Grab	IFC tributary, instream
15	DMF	Isco, independent	Edge-of-field
16		Grab	IFC mainstem, instream
17	SMF	Isco, slave to Station 18	Upstream of SMF site, edge-of-field
18	SMF	Isco, master of Station 17	Downstream of SMF site, edge-of-field
19		Grab	IFC mainstem, instream
20		Grab	IFC mainstem, instream
21	REF	Isco, independent	Edge-of-field
22	IMP	Grab	Upsteam of IMP lake, instream
23		Grab	IFC mainstem, instream
24	FLT	Grab	Downstream of FLT site
25	FLT	Grab	Downstream of FLT site
26	FLT	Grab	Upstream of FLT site
27	FLT	Grab	Upstream of FLT site
28	FLT	Grab	IFC mainstem, instream
29	FLT	Grab	IFC mainstem, instream

[z] IMP = Impoundment, NMF = North Manure Field, PST = Pasture, WIN=Wintering, DMF=Dairy Manure Field, SMF=South Manure Field, REF=Reference, FLT = Feedlot.
[y] Station 2 was washed out in 2010 and not re-installed.
[x] Station 6 discontinued in 2009.
[w] Station 7 was an IFC mainstem, instream station and was discontinued in 2009.

Table 2.8. Water monitoring stations at Lower Little Bow Field (LLB) and Battersea Drain Field (BDF).

Site	Station	Description	Location
LLB	101	Isco, independent	Edge-of-field
BDF	201	Isco, master to 203, 204, 205, 206	Upstream of BDF site, instream
BDF	202	Isco, slave to 203, 204, 205, 206	Downstream of BDF site, instream
BDF	203	Isco, master to 202, 201	Edge-of-field
BDF	204	Isco, master to 202, 201	Edge-of-field
BDF	205	Isco, master to 202, 201	Edge-of-field
BDF	206	Isco, master to 202, 201	Edge-of-field

Table 2.9. Water monitoring stations in the Whelp Creek Sub-watershed.

Station	BMP site[z]	Description	Location[y]
301		Isco and grab	Watershed outlet
302	NPS	Grab[y]	Downstream of NPS site, instream
303	NPS	Grab[y]	Upstream of NPS site, instream
304		Grab	WHC tributary, instream
305		Grab	WHC tributary, instream
306	EFD	Isco, independent	Downstream EFD site, instream
307	EFD	Isco, independent	Edge-of-field
308	EFD	Isco, independent	Upstream of EFD site, instream
309	WFD	Isco, independent	Edge-of-field
310	NFD	Isco, independent	Downstream NFD site, instream
311	NFD	Isco, independent	Edge of field, west
312[x]	NFD	Isco, independent	Edge of field, east
313	NFD	Isco, independent	Upstream of NFD site, instream
314	SFD	Isco, independent	Downstream of SFD site, instream
315	SFD	Isco, independent	Upstream on south tributary of SFD site, instream
316	SFD	Isco, independent	Upstream on north tributary of SFD site, instream
317	REF1	Isco, independent	Upstream of REF1 site, instream
318	REF1	Isco, independent	Downstream of REF1 site, instream
319	REF2	Isco, independent	REF2, edge of field
320		Grab	Diversion to Lacombe Lake
323[w]	SPS	Grab	North drainage of SPS site, edge of field
324	SPS	Isco	South drainage of SPS site, edge of field

[z] NPS = North Pasture, EFD = East Field, WFD = West Field, NFD = North Field, SFD = South Field, REF1 = Reference 1, REF2 = Reference 2, SPS = South Pasture.
[y] Isco samplers were used in 2008, removed in 2009 at the request of the landowner.
[x] Station 312 discontinued in 2009.
[w] Station 323 discontinued in 2009.

Water samples taken by the grab sampling method were collected by submerging a water-sampling pole with a 1-L bottle into stream water and triple rinsing before taking the final sample volume (Figure 2.25). Grab samples were taken in the middle of the stream and from below the surface to about half the depth of the stream.

In addition to the watershed-wide sampling, grab samples were taken prior to the installation of Isco samplers in 2007 and during times of technical failure of the Isco samplers (e.g., frozen intake lines or dead batteries). If a grab sample was taken at a BMP site, all other sites to which the sample was to be compared were also grab sampled. Sampling dates with inconsistent sample methodology (grab vs. Isco) were not used in statistical comparisons.

Figure 2.25. Grab sampling with a pole and sample bottle at the Battersea Drain Field.

2.8.3 Laboratory Analysis

The water samples collected using grab bottles or Isco composite bottles were sub-sampled into smaller plastic bottles provided by the laboratory for specific analyses (Figure 2.26, Table 2.10). Sub-sample bottles, except for the bacteria bottle, were triple rinsed with sample water before filling. The bacteria bottles were filled without triple-rinsing because $Na_2S_2O_3$ preservative was in the bottles. After filling, some bottles had acid preservative added (Table 2.10). A 1-L amber glass bottle was filled for chlorophyll *a* analysis during every other watershed wide sampling event.

The filled water sample bottles from each station were packed in coolers on ice in the field and transported to the nearest courier for delivery to the laboratory the next morning. Samples were analyzed by ALS Laboratory Group in Calgary from 2007 to 2009 and by Exova in Calgary from 2010 to 2012. If sampling occurred on weekends or holidays when the courier could not deliver the samples by the next morning, samples were shipped by Greyhound bus or driven to Calgary by staff in order to meet laboratory hold times.

Figure 2.26. Water samples being (a) sub-sampled in the field and (b) bottles for specific lab analysis.

Table 2.10. Laboratory bottles used for water sampling.

Parameter type	Bottle type	Tripled rinsed	Preservative
Routine[z]	500-mL polyethylene	yes	none
Nutrient[y]	250-mL polyethylene	yes	2 mL 9 M sulphuric acid[x]
Total nitrogen	250-mL polyethylene	yes	2 mL 6 M hydrochloric acid[x]
Bacteria	300-mL polyethylene	no	0.2 g sodium thiosulphate[w]
Chlorophyll *a*	1-L amber glass	no	none

[z] Routine analysis included NO_2-N, NO_3-N, Ca, Mg, Na, K, $CaCO_3$, OH, CO_3, HCO_3, Cl, pH, EC, TDS, and TSS.
[y] Nutrient analysis included NH_3-N, TDP, TP, and DRP.
[x] Acid solutions were prepared by diluting concentrated acids 1:1 with water.
[w] Preservative was in the bottle prior to filling with sample water.

The change from ALS Laboratory Group to Exova did not affect data as laboratory methods were consistent for nearly all parameters, except that ALS Laboratory Group analyzed total Kjeldahl nitrogen (TKN) and calculated total nitrogen (TN) (Equation 2.5) and Exova analyzed TN and calculated TKN (Equation 2.6). The quality control and assurance data indicated there was good agreement and no significant differences between the two laboratories (Appendix 2).

$$TN = TKN + NO_2\text{-}N + NO_3\text{-}N \qquad \text{Equation 2.5}$$

$$TKN = TN - NO_2\text{-}N - NO_3\text{-}N \qquad \text{Equation 2.6}$$

Where:
TN = total nitrogen concentration (mg L^{-1})
TKN = total Kjeldahl nitrogen concentration (mg L^{-1})
NO_2-N = nitrite nitrogen concentration (mg L^{-1})
NO_3-N = nitrate nitrogen concentration (mg L^{-1})

Samples were handled specifically upon arrival at the laboratory with regard to filtering, storage, and hold times depending on the required analysis (Table 2.11). Hold times were consistently met for nearly all parameters, except for microbiology analysis of automated samples. The Isco samples were a composite sample collected for a maximum of 24 h and then shipped to the laboratory. This often meant that part of the composite sample often exceeded the 24-h hold time. Because of this, comparing absolute bacteria values with guidelines was not appropriate; however, relative comparisons to evaluate the BMPs were still feasible. Microbial samples collected by grab sampling met the 24-h hold time.

Blanks filled with deionized water, as well as prepared standards of known phosphorus (P) and N concentrations, were submitted with a random batch of samples once a month to the laboratory as part of a quality assurance/quality control program. Additional information about quality assurance and quality control is in Appendix 3.

In terms of water quality, the focus of the study was on nutrient loss in runoff water. Nitrogen and P parameters were analyzed because of their potential negative environmental impacts (Table 2.11). Additionally, total suspended solids (TSS), pH, and electrical conductivity (EC) were measured as routine water quality parameters. Biological parameters were also measured including chlorophyll *a*, fecal coliforms, and *Escherichia coli* (*E. coli*). The latter two biological parameters were included as indicators of fecal contamination because the study sites had the presence of livestock manure. Chloride (Cl) was included because manure is often a source of chloride. Chloride is not biologically or chemically active in the soil, and Cl from manure can be used as a tracer (Chang et al. 1991).

2.8.4 Data Analysis

Water chemistry data were compiled in a master water quality database. Values that were less than the laboratory method detection limits (MDL) were replaced with half of the detection limit value. Organic nitrogen, dissolved in organic nitrogen, and particulate phosphorus were calculated by the following equations:

Table 2.11. Standard procedures for water sample analysis used by ALS Laboratory Group and Exova.					
Sub-sample bottle	Test description	Sample preservation	Laboratory processing protocols	Analytical method	References[z]
Routine	pH	Chill to 4°C	1[y]	Electrode	APHA 4500-H^+ (B)
Routine	Chloride[x]	Chill to 4°C	1	Ion chromatography	APHA 4110 (B)
Routine	Conductance (EC)	Chill to 4°C	1	Conductivity cell	APHA 2510 (B)
Routine	Total suspended solids (TSS)	Chill to 4°C	2	Glass-fiber filter, gravimetric	APHA 2540 (D)
Routine	Nitrate nitrogen (NO_3-N)	Chill to 4°C	1	Ion chromatography	APHA 4110 (B)
Routine	Nitrite nitrogen (NO_2-N)	Chill to 4°C	1	Ion chromatography	APHA 4110 (B)
Nutrients	Orthophosphate (PO_4-P)[w]	Chill to 4°C with H_2SO_4 to pH<2.0	1	Auto-colorimetry	APHA 4500-P (E)
Nutrients	Total dissolved phosphorus (TDP)[w]	Chill to 4°C with H_2SO_4 to pH<2.0	1	Persulfate digestion, auto-colorimetry	APHA 4500-P (B.5), (E)
Nutrients	Ammonia nitrogen (NH_3-N)	Chill to 4°C with H_2SO_4 to pH<2.0	2	Auto-colorimetry	APHA 4500-NH_3 (G)
Nutrients	Total phosphorus (TP)	Chill to 4°C with H_2SO_4 to pH<2.0	3	Persulfate digestion, auto-colorimetry	APHA 4500-P (B.5), (E)
Nutrients	Total Kjeldahl nitrogen (TKN)[v]	Chill to 4°C with H_2SO_4 to pH<2.0			
Total N	Total nitrogen (TN)[u]	Chill to 4°C with HCl to pH<2.0	3	Sulfuric acid digestion, auto-colorimetry	APHA 4500-N_{ORG} (C) APHA 4500-NH_3 (G)
Microbiology	Total coliforms	Chill to 4°C	2	Chromogenic substrate test	APHA 9223 (B)
Microbiology	*Escherichia coli*	Chill to 4°C	2	Chromogenic substrate test	APHA 9223 (B)
Chloro-A	Chlorophyll *a*	Chill to 4°C	3	90% Acetone Ext. and UV/VIS spectrophotometer	APHA 10200 (H)

[z] American Public Health Association 1989, 1995, and 1998a-g.
[y] 1. Filter immediately upon arrival using a 0.45-µm membrane filter. Keep cool at 4 °C. Analyze within 24 h.
2. Do not filter sample. Keep cool at 4°C. Analyze within 24 h.
3. Do not filter sample. Keep cool at 4°C. Analyze within 48 h.
[x] Added in 2009.
[w] ALS Lab analyzed from routine bottle.
[v] Analyzed by ALS Lab but calculated by Exova.
[u] Analyzed by Exova but calculated by ALS Lab.

$$ON = TKN - NH_3\text{-}N \qquad \text{Equation 2.7}$$

$$DIN = NO_3\text{-}N + NO_2\text{-}N + NH_3\text{-}N \qquad \text{Equation 2.8}$$

$$PP = TP - TDP \qquad \text{Equation 2.9}$$

Where:
ON = organic nitrogen concentration (mg L^{-1})
TKN = total Kjeldahl nitrogen concentration (mg L^{-1})
NH_3-N = ammonia nitrogen concentration (mg L^{-1})
DIN = dissolved inorganic nitrogen concentration (mg L^{-1})
NO_3-N = nitrate nitrogen concentration (mg L^{-1})
NO_2-N = nitrite nitrogen concentration (mg L^{-1})
PP = particulate phosphorus concentration (mg L^{-1})
TP = total phosphorus concentration (mg L^{-1})
TDP = total dissolved phosphorus concentration (mg L^{-1})

Load values were calculated using chemistry and water flow data. For each water sample analyzed, the volume of water representative of that sample was determined. For automated Isco samples, the total volume was during the period the Isco sampled (i.e., maximum of 24 h). For grab samples, the volume used was either from start to finish of the runoff period during which the sample was taken, or for the period halfway from the previous grab sample to the next grab sample. When Isco samples were followed by grab samples, or vice versa, professional judgment was used to partition water volume among the samples. Volumes of water that could not be associated to a sample (e.g., events where no samples were collected) were assigned water chemistry values from a sample collected nearest in time and from a similar event type.

The water quality parameter concentrations for water flow through the edge-of-field circular flumes were well represented, as composite samples were collected during events. In contrast, only periodic water samples were collected at instream stations, and as a result, the water quality parameter concentrations assigned to a specific volume of water may be less accurate. Loads were only calculated for monitoring stations that had continuous flow data. Yearly flow-weighted mean concentrations (FWMCs) were calculated for the outlets of IFC (Stations 1) and WHC (Station 301) by dividing the total load for all events by the total flow volume for all events during the year.

Statistical analysis of the water quality data for BMP sites varied depending on the monitoring design. For sites with edge-of-field monitoring stations (e.g., Station 4 at the NMF site in IFC Watershed), average concentration of parameters, either for all runoff events or individual runoff types (e.g., snowmelt), were compared between the pre- and post-BMP periods. For sites with upstream-downstream monitoring stations (e.g., Stations 8 and 5 at the PST site in IFC Watershed), the average relative difference between upstream to downstream stations were compared between the pre- and post-BMP periods. A population of differences was created by subtracting the upstream concentration value from the downstream concentration value for each sampling day. A difference was not calculated if only one of the stations was sampled and could not be paired with the other station on a given day. Also, paired samples not sampled by the same method (grab or

Isco) on the day of sampling were not used to calculate differences. The averages of calculated differences for either all runoff events or individual runoff types (e.g., snowmelt) were then compared between the pre- and post-BMP periods. Essentially the upstream station served a relative control. If water quality deteriorated from upstream to downstream in the pre- and post-BMP periods, but the difference between upstream and downstream in the post-BMP period was smaller, then the conclusion was made that the BMP had a positive effect.

Statistical analyses of the water samples were completed using SAS version 9.2 (SAS Institute Inc. 2008). The Univariate procedure was used to test the distribution of the data and the Means procedure was used to generate descriptive statistics. Differences between the pre-BMP and post-BMP periods and event types were tested using the nonparametric Mann-Whitney U (a modified Wilcoxon Rank Sum test) statistical test. For sites where the BMP started in 2008 (LLB, BDF, WIN, IMP) chloride was not included in the BMP period analyses because it was added to the analysis in late July 2008 and there were not enough pre-BMP data. A significance level of $P<0.1$ was used in this study.

2.9 Soil

2.9.1 Characterization Samples

To help describe the BMP sites, soil characterization samples were collected at most sites to describe and classify the major soil types to the sub-group or series level. The sites where soil characterization samples were not collected included the IMP, FLT, FEN, OSW, and CAT sites. Sample locations were determined using existing soils information (e.g., Agricultural Region of Alberta Soil Inventory Database and Level 3 land irrigability maps) and air-photo interpretation. The number of cores sampled varied from two to six cores depending on the site. A truck-mounted, hydraulic coring unit (Figure 2.27a) was used to obtain cores to a maximum depth of 2.7 m. At each sample point, one core sample was collected and characterized using the Canadian System of Soil Classification (Soil Classification Working Group 1998). Soil profile descriptions included horizon sequences, soil structure, gleying, soil colour, effervescence, parent geologic material, texture, moisture status, and presence and type of bedrock. Site features such as slope class, land use, erosion, and stoniness were also recorded. A sample was collected from each soil horizon. The samples were air dried, ground (<2 mm), and sent to the laboratory for analysis (Table 2.12). The soil characterization results are in Appendix 4.

2.9.2 Agronomic Samples

Agronomic soil samples were collected each year during the study to determine nutrient status in the soil surface (0 to 15cm), prior to the main runoff periods at BMP sites with annual crop fields. Samples were collected in the spring after seeding and the application of inorganic fertilizer or manure and again in the fall after all field activities were completed. The spring samples represented the surface soil conditions during spring and summer rainfall events, and the fall soil samples represented surface soil conditions during snowmelt runoff in the following spring.

Sampling points were generally based on a 200- by 200-m grid, which covered the drainage area of the BMP sites. Variations of this grid are described in the specific BMP subsections. A GPS unit was used to initially locate the sampling points. In subsequent years, samples were collected 5 m from the original points in different directions (i.e., north in 2008, south in 2009, east in 2010, west in 2011, and original location in 2012). Spring sampling was carried out using a Dutch auger (Figure 2.27b) or an Oakfield probe. Fall sampling was carried out using a Dutch auger, Oakfield probe, or a truck-mounted, hydraulic coring unit. At each sampling point, five, 0- to 15-cm core samples were collected. The five core samples were mixed together and a 1-kg sub-sample was kept for analysis. Samples were air dried, ground (< 2 mm), and sent to the laboratory for analysis (Table 2.12).

In spring 2011, two sets of agronomic soil samples were collected at seven BMP sites (NMF, SMF, REF, WFD, SFD, REF1, and REF2). One set was collected before seeding and the second set was collected after seeding to determine if the addition of commercial fertilizer during seeding had a measurable effect on plant available N and P in the soil. Statistical analyses of the pre- versus post-seeding samples were completed using SAS version 9.2 (SAS Institute Inc. 2008). The Univariate procedure was used to test the distribution of the data and the Means procedure was used to generate descriptive statistics. Differences between pre- and post-BMP periods were tested using the Least Squared Means test in the Mixed procedure with unstructured variance components with the repeated and pdiff options. A significance level of $P < 0.1$ was used.

Figure 2.27. Soil sampling with (a) a truck-mounted, hydraulic coring unit and (b) a Dutch auger.

Table 2.12. Standard procedures for soil sample analysis used by ALS Laboratory Group and Alberta Agriculture and Rural Development (ARD) Water Assessment Unit .

Parameter	Sample type[z]	Analytical method	References
		ALS Laboratory Group	
Extractable NO_3-N	1,2,3,4	2M KCl extraction solution Auto-colorimetry	Carter 1993 (Methods 4.3 and 4.4)
Extractable NH_4-N	1,2,3,4	2M KCl extraction solution Auto-colorimetry	Carter 1993 (Methods 4.3 and 4.4)
Extractable PO_4-P (Soil-test P) and K	1,2,3,4	Modified Kelowna extraction solution Auto-colorimetry	Qian et al. 1994
pH, EC, Ca, Mg, Na, K	3	Saturated paste extraction Measure soil pH EC – conductivity meter Ca, Mg, Na and K – ICP-AES	Carter 1993 (pp.141-142 and pp.162-164)
SAR	3	Calculated from saturated paste data	
Total P	3	Digestion with combination of nitric acid and perchloric acids ICP-AES	Kuo 1996
Total N	3	Carlo Erba high temperature (900°C) combustion	Bremner 1996 (Dumas method)
Organic matter	3	Loss on Ignition at 375°C	McKeague 1978
Sand, silt, clay	3	Soil sample soak in 50 mL of 1N sodium hexmetaphosphate solution with 150 mL distilled water overnight. Particle density and temperature of soil sample, along with a blank, are taken at 30 s, 60 s, and 24 h.	Carter 1993 (pp. 508-509)
		ARD Soil and Water Assessment Unit	
Cl	4	Saturated paste extraction - CFA	Rhoades 1982
Sand, silt, clay	5	Bouyoucos – hydrometer readings taken at 40 sand 2 h. (ARD)	Carter 1993 (pp. 499-511)
	3	Bouyoucos – hydrometer readings taken at 30 s, 60 s, and 24 h (ALS)	

[z] Sample type: 1 = Agronomic, 2 = Soil -test, 3 = Characterization, 4 = Deep Core, and 5 = Alberta Irrigation Management Model.

2.9.3 Soil-test Samples

Soil-test samples were collected to determine the nutrient status from the 0- to 60-cm layer and were used to develop nutrient management recommendations at BMP sites with annual crop fields during the post-BMP period. Samples were collected in the fall after harvest and other field activities were completed. These samples were generally collected in conjunction with the fall agronomic sampling. A transect sampling method was used with approximately five transects per quarter section. The variations due to different field sizes are discussed in the specific BMP subsections. The transect method captured topographic variation within the field and each transect had a high, mid, and low slope sampling point. Samples were collected from three increments soil layers: 0 to 15 cm, 15 to 30 cm, and 30 to 60 cm. Soil collected from each incremental layer from all the sample points in the field was combined, mixed, and sub-sampled (1 kg), yielding three samples per sampling time for a given site, or quarter section, one for each incremental soil layer. Samples were air dried, ground (<2 mm), and sent to the laboratory for analysis (Table 2.12). Soil-test samples were collected from the required sites from 2008 to 2011. In 2008 and 2009, the composite samples were sub-sampled three times and sent to the laboratory for analysis (i.e., triplicate analysis per sample). In 2010 and 2011, the composite samples were only sub-sampled once for analysis.

2.9.4 Deep Core Samples

Deep core samples were collected for the purpose of determining nutrient status through the soil profile that may impact groundwater quality. Samples were taken at the BDF field site, the PST and DMF sites in IFC, and nearly all BMP sites in WHC except for the NPS and SPS sites. Three locations were sampled in each field based on topography: lowland, highland, and level area. Generally, samples were collected in 30-cm increments to a depth of 3 m if possible. The exception was for the BDF site in 2011 and 2012 when samples were collected from 0- to 15-cm, 15- to 30-cm, and then in 30-cm increments. Sampling was usually carried out in conjunction with the fall agronomic sampling using a truck-mounted, hydraulic coring unit. The samples were air dried, ground (<2 mm), and sent to the laboratory for analysis (Table 2.12).

2.9.5 AIMM Samples

Soil samples were collected to obtain moisture and texture values to initialize the Alberta Irrigation Management Model (AIMM) as part of the irrigation BMP plans at the BDF and LLB sites. At the start of the BMP period in 2009, soil texture was measured once; whereas, soil moisture was measured each year prior to the irrigation season during the BMP period. Additional soil moisture samples were collected during the irrigation season to validate the model predictions. Samples were collected from representative areas within the fields and locations were recorded with a GPS unit to allow for re-sampling through the irrigation season. Samples were collected from the 0- to 25-cm, 25- to 50-cm, 50- to 75-cm, and 75- to 100-cm soil layers. A composite sample was prepared for each layer and a sub-sample placed in pre-weighed moisture tins. Samples were weighed and then oven dried at 105°C for 24 h, after which they were re-weighed and soil moisture content determined. Soil texture analysis was carried out on samples collected in 2009 from both field sites using the same sampling method as described for the soil moisture samples.

2.9.6 Soil Analysis

Most soil samples collected were analyzed by ALS Laboratory Group in Saskatoon, Saskatchewan. Occasionally samples were analyzed by the Alberta Agriculture and Rural Development (ARD) Soil and Water Assessment Unit, in Lethbridge, Alberta (Table 2.12). The latter laboratory analyzed the soil moisture and texture for the AIMM samples.

Soil samples were placed onto aluminum plates to air dry for about 7 d. Large lumps were broken and plant material and stones removed. After drying, samples were ground using a stainless-steel, rotation-drum grinder, or in some cases, a jaw-type crusher for cemented samples. Ground samples were passed through a 2-mm sieve. Some sandy soils were passed through the sieve without grinding (Au and Kadijk 2005). Samples were bagged and sent to the laboratory for analysis (Table 2.12).

2.10 Manure

2.10.1 Manure Sampling

Manure samples were collected either just prior to manure application or at the time of manure application at many of the BMP sites in the study watersheds. This generally applied to most of the annually cropped BMP sites. During the course of the study, manure samples were collected for the SMF, DMF, NFD, WFD, EFD, SFD, BDF, and LLB sites. Manure types sampled included liquid hog, liquid dairy, solid chicken, and solid beef manure. Sampling strategy varied depending on the site conditions and manure type. Generally, multiple sample replicates were collected ranging from 2 to 18 samples. The exception was the DMF where one sample was collected per sampling time. Solid manures were generally sampled from stockpiles. A solid manure sample was obtained by placing a minimum of three grab samples into a container to create a composite sample from which a subsample (about 1 kg) was removed after mixing. Additional composite samples were prepared and subsampled to obtain replicate samples. Solid manure samples were placed into plastic bags. Liquid manure samples were obtained either from the liquid manure spreader just prior to land application or when the manure spreader was filled at the manure storage facility. Generally, a liquid sample was initially collected in a large container (20 L) from which a smaller sample was obtained and placed into a 1-L plastic bottle. All solid and liquid manure samples were stored frozen and sent to the laboratory for analysis.

2.10.2 Manure Analysis

Manure samples were sent to the ALS Laboratory Group in Saskatoon, Saskatchewan for water and nutrient content analysis. All manure samples were analyzed for the content of water, extractable ammonium nitrogen, total nitrogen, total phosphorus, total potassium, and total sulphur (Table 2.13). In addition, liquid manure samples were analyzed for total sodium content.

Table 2.13. Standard procedures for manure analysis used by ALS Laboratory Group, Saskatoon, Saskatchewan.

Parameter	Analytical method	Reference
Moisture	Oven dried at 105°C overnight.	Hoskins et al. 2003
Ammonium nitrogen (NH_4-N)	Extract sample with 2.0 M KCl solution. Determine NH_4-N by Auto-colorimetry.	Peters et al. 2003
Total nitrogen	Pretreat sample with Devarda's alloy, follow by sulphuric acid digestion with $CuSO_4$ and K_2SO_4. Determine total N by titration.	Liao 1981
Total phosphorus, potassium, and sulphur	Nitric/perchloric acid digestion. Determine total P, K, and S by ICP.	Environmental Protection Agency SW-846 Method 3050 (USEPA 2013a)

2.11 Riparian Quality

2.11.1 Cows and Fish Assessment

In 2007, the Alberta Riparian Habitat Management Society (known as Cows and Fish) completed riparian health assessments at the IMP, WIN, and PST sites in the IFC Watershed before the livestock management BMPs were implemented. The survey results for the riparian areas of these pastures were used as a baseline riparian health score. Cows and Fish then completed post-BMP riparian evaluations in 2012 to assess the riparian health status of each pasture at the end of the study. The information was used in the analysis of BMP effectiveness and was provided to individual landowners to aid in their land management decisions.

During the assessments, the entire perimeter of the IMP lake and reaches on both sides of Indianfarm Creek at the WIN and PST sites were evaluated. Riparian health was scored by combining values related to vegetation cover, soil, and hydrology conditions. Vegetation cover values were derived based on the percentage and type (e.g., preferred or invasive) of plant cover in the riparian zone. Soil/hydrology values were generated based on stream bank root mass, presence of bare ground, occurrence of physical alterations, and channel incisement. The vegetation and soil/hydrologic health categories were rated individually and were combined to give overall site health ratings as Healthy, Healthy but with Problems, or Unhealthy.

2.11.2 Annual Transect Assessment

From 2008 to 2012, riparian transect surveys (Figure 2.28) were completed annually at the IMP, WIN, and PST sites to evaluate riparian quality and monitor changes as a result of livestock BMPs implemented at these sites. Surveys were conducted at similar times each year so the stage of vegetative growth was comparable among years. All transects were surveyed in 2008 and 2012. A subset of transects at each site were surveyed from 2009 to 2011. Specific details for each of these BMP sites are presented in Section 3.

Transects were located by measuring the length of the creek or tributary within the BMP site area and dividing the length into 70- to 100-m sub-sections. Within each sub-section, a random number from 1 to 70 or from 1 to 100 was chosen as the starting point of the transect. The IMP, WIN, and PST sites had 7, 12, and 20 transects, respectively. Transects crossed the creek or tributary perpendicularly at the selected locations with approximately half of each transect on either side. The transects varied in length from 4 to 30 m on either side of the creek, depending on the width of riparian and transitional zones and where the upland vegetation started. Transect start and end point coordinates on each side of the creek were recorded using a handheld GPS unit and field survey pins were positioned to ensure consistent locations for annual surveys. Photographs were taken of each transect to archive visual changes in riparian condition with time.

Vegetation was surveyed using 1-m^2 quadrats (Figure 2.28b) placed every 2 m along each transect starting at the edge of the water. Within each quadrat, individual species were recorded for presence and the number of specific plants was counted. Percent coverage of each species, leaf litter coverage, and bare ground were documented. Because of the difficulty of counting individual plants, grass species were recorded only as percent cover.

In 2010, a control site was established with four transects to measure natural variability in the riparian areas of IFC without BMP implementation. As most riparian areas of IFC were grazed, a parcel of land with consistent annual grazing management was selected 65 m upstream from Station 12. Control transects were surveyed annually using the same procedures as the other transects. Results from the control site are presented in Appendix 5.

A one-way PERMANOVA (permutational multivariate analysis of variance) with post-hoc pairwise comparisons between all groups, performed in PAST (Hammer et al. 2001), was used to test whether riparian communities were different, in terms of the percent cover of species, before and after the implementation of the BMPs in each vegetation zone (riparian, transition, or upland). Although there were two categorical variables characterizing plots (year and zone), a two-way PERMANOVA could not be performed in PAST as the design was not balanced (i.e., there were not the same number of plots in each year × zone combination). Instead, the one-way

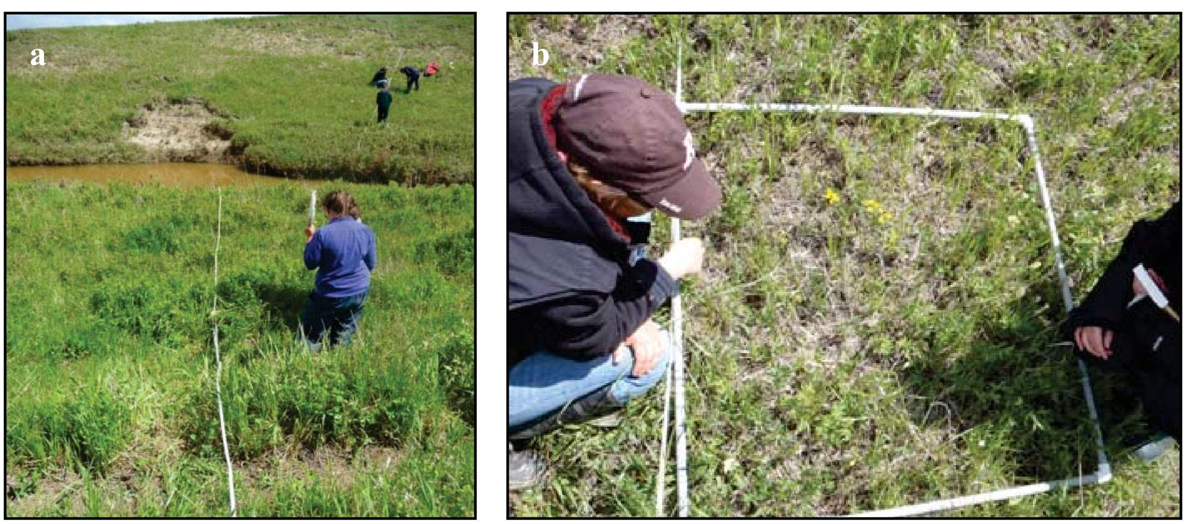

Figure 2.28. Conducting riparian surveys using (a) transects across the creek and (b) 1-m^2 quadrats.

PERMANOVA performed assessed one-categorical variable that comprised year × zone combinations (for example, 2008 riparian plots, 2008 transition plots, 2012 riparian plots, etc.). Differences between groups were then assessed by examining pairwise PERMANOVAs between all pairs of groups, provided as a post-hoc test in PAST. *P*-values of these post-hoc tests were reported with a Bonferroni correction to account for the fact that multiple comparisons were performed. This correction gives a conservative *P*-value for differences between groups (Legendre and Legendre 1998). Although all pairwise comparisons were performed, only those representing changes within each zone before and after implementation are discussed as it was not of interest here to assess whether communities were different between zones within the same or different years. In these analyses, riparian data from 2008 and 2012 were used to represent conditions before and after BMP implementation, respectively, although 2009 data were used for Transects 6 and 7 at the IMP site. Percent cover was used instead of counts because counts were not obtained for all plots, and plots were characterized by vegetation zone to account for differences in community attributable to soil moisture. Specifications for the PERMANOVAs included 9999 permutations, and Bray-Curtis distance as a measure of community similarity as this is typical for community analyses (Legendre and Legendre 1998). For each zone, whether significant differences were found or not before and after BMP implementation, SIMPER (similarity percentage) analysis, again using Bray-Curtis distance, was performed to assess which species contributed most to dissimilarities in community structure. This analysis reports each species' contribution, in terms of a percentage, to the overall similarity (or dissimilarity for Bray-Curtis distance) among plots.

In addition to species cover, species richness (SR), evenness (E), and Shannon's diversity were also calculated for each plot. These parameters were used to assess plant community quality or health in terms of number of different species and the proportional area distribution among species. For ease of interpretation, Shannon's diversity was converted to effective diversity (ED), or the number of equally common species that would give a particular value of the Shannon's index, by taking the exponent of the Shannon's index (Jost 2006). Differences between species richness, evenness, and effective diversity between years were assessed using an ANOVA-style approach in SAS/STAT of SAS 9.2 (SAS Institute Inc. 2008). Zone was included as a blocking variable to control for differences in SR, SD, and E that may be attributable to differences in the number of plots per zone in each year. Different zones may have differences in SR, ED, and E caused by moisture conditions rather than BMP effects, so any changes in zone distribution needed to be accounted for. Because zone was a blocking variable, differences in zones are not discussed, and the least-squares means for pre- and post-BMP years were presented as averages across zones. The interaction term between zone and year was originally included, but removed if not significant at a type I error rate of 0.05. For Transects 6 and 7 at the IMP site, data were normally distributed, so a general linear model (a two-way ANOVA) was used. For the BMP transects, the same approach was used for E, as the residuals were normally distributed. For ED and SR, however, the data were right skewed, so were assessed using generalized linear models with the same structure, but with a Poisson error distribution and log link function. For the PST site, ED was normally distributed so a general linear model was used. Species richness and E were right skewed, so a generalized linear model with Poisson distribution and log link function was used. For the WIN site, E was normally distributed, so a general linear model was used. Species richness and effective ED were right skewed, so generalized linear models with a Poisson distribution and log link function were used. The fit of the data to the model specifications was assessed using the deviance to degrees of freedom ratio, which should be close to 1 (Myers et al. 2002). Least-squares means (LSMs) were used to calculate means for each level of the two categorical variables.

The data collected from pre- and post-BMP surveys were compared to evaluate riparian quality in three aspects:

- Riparian zone comparisons – PERMANOVA tests on quadrats taken from the riparian, transition, and upland vegetative zones were performed. All species common to 2008 and 2012 were assessed, with the exception of 2009 and 2012 for the IMP site Transects 6 and 7.
- Species richness, evenness and effective diversity – these values were calculated and compared for each zone for the 2008 and 2012 data at all sites, except for the IMP site Transects 6 and 7.
- Cows and Fish riparian health assessment – the 2012 riparian health status values were compared to the 2007 baseline survey to indicate how land management change impacted riparian function.

2.12 Rangeland Quality

2.12.1 Rangeland Transects

Beginning in 2007, rangeland-transect surveys and health assessments (Figure 2.29) were carried out annually at the PST site to evaluate rangeland quality. Surveys were conducted in July each year so that stage of vegetative growth was comparable among the years. Methods used were based on Adams et al. (2005) and ASRD (2007).

Vegetation inventory was surveyed using a 0.25-m^2 Daubenmire sampling frame (Figure 2.29b) placed every 2-m along 30-m transects starting at 0 m (ASRD 2007). Six transects were assessed in 2007 and four more transects were added in 2008 for a total of 10 transects. These 10, 30-m transects were located in each plant community polygon and in areas where vegetation represented

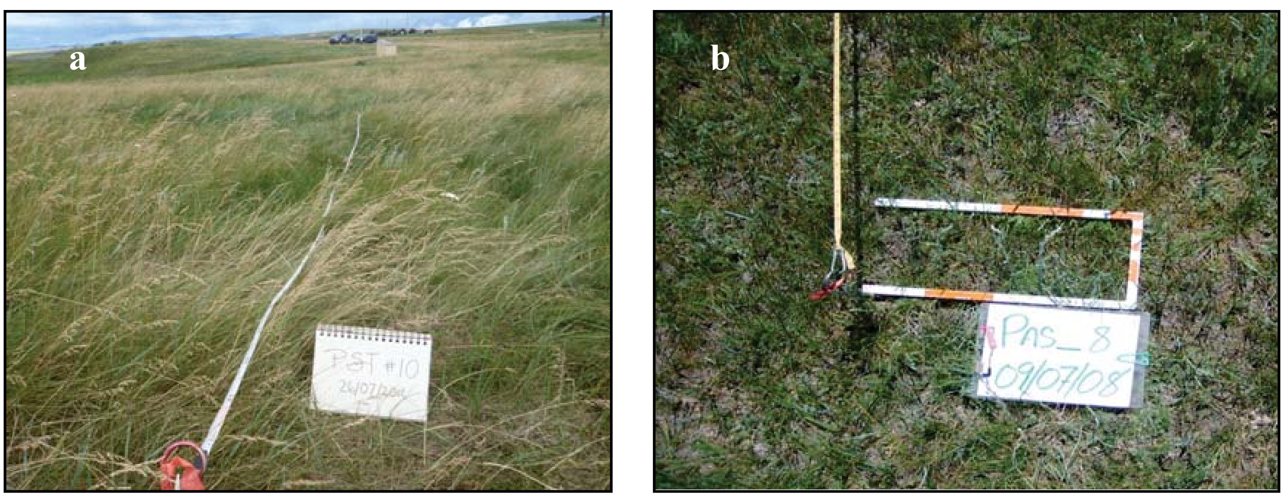

Figure 2.29. Evaluating rangeland quality along (a) a transect with (b) a 0.25-m^2 Daubenmire frame at the Pasture site in the Indianfarm Creek Watershed.

the whole pasture. When transects were on a slope, they were orientated parallel to the contour of the slope. Transect start and end coordinates were marked with a handheld GPS unit and field survey pins were positioned to ensure consistent locations for annual surveys. Photographs were taken of each transect to archive visual changes in rangeland condition with time. The presence and percent cover of each vegetation species was recorded using a Prairie MF5 vegetation inventory form (ASRD 2007). Percent cover of litter, total vegetation, exposed ground, and moss and lichen cover, as well as terrain profiles and additional notes on vegetation, were also recorded. Averages were calculated from fifteen Daubenmire-frame plots per transect.

Range health scores were calculated each year to obtain a cumulative measure of the health of the pasture based on factors that affect the area selected to monitor (Adams et al. 2005). In this assessment, five questions were answered based on the transect data that were collected and knowledge of the pasture. The five questions or score categories were (1) ecological status (i.e., presence of key species of plant communities), (2) plant community structure, (3) litter cover and distributions (important for the retention of moisture), (4) site stability (soil erosion and bare soil), and (5) presence of noxious weeds. The scores from the five questions were summed and a percentage calculated out of 60, which is the maximum total score possible, using the Grassland Range Health Assessment Score Sheet (Adams et al. 2005). The rangeland health score was used to determine the health rating of either Healthy (75 to 100%), Healthy with Problems (50 to 74%), or Unhealthy (<50%) (Adams et al. 2005).

2.12.2 Production Cages

To complement the rangeland transects at the PST site in the IFC Watershed, 11 production cages were placed in the pasture prior to grazing in 2008, with one cage near each rangeland transect. The number of cages was reduced to 10 from 2009 to 2012. Production cages were also installed at the NPS and SPS sites in the WHC Sub-watershed. Three cages were used at the NPS site and nine cages were used at the SPS site. The production cages allowed for comparison of vegetation response and growth of the ungrazed area inside the cage to the grazed area outside the cage to determine whether the livestock management BMPs had an effect on grass, forb, and litter production.

The production cages covered an area approximately 1 m^2 in size (Figure 2.30a). The cages were constructed from thick, metal wire, held in place with re-bar pegs. The vegetation within the caged areas was clipped annually in late summer using a 0.25- m^2 frame (Figure 2.30b). Within each frame, grass, forbs, and litter were cut and separated into perforated paper bags. Vegetation was also clipped from an area outside the cage that closely resembled the species composition inside the cage using the same method as clipping inside the cage. The bags of plant material were dried at 35˚C for 12 d in a drying room and weighed. Dry-weight biomass was then calculated in kilograms per hectare. After clipping each year, the production cages were moved a few metres from the previously clipped area.

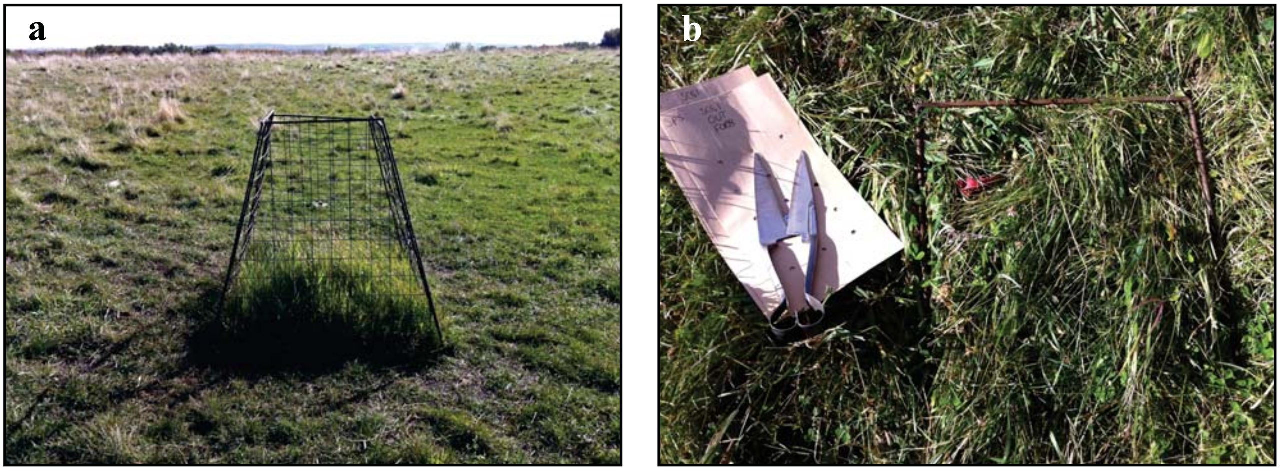

Figure 2.30. South Pasture site in the Whelp Creek Sub-watershed showing (a) a production cage and (b) 0.25-m^2 frame used to delineate an area of vegetation to be clipped.

The average biomass between the caged and non-caged areas were compared. The caged area results provided a indication of total biomass production without grazing; whereas, the non-caged area showed the amount of biomass at the end of the grazing season.

To assess the BMP effect, the average differences between the caged and non-caged areas were compared between the pre- and post-BMP periods. Statistical analysis was completed using SAS version 9.2 (SAS Institute Inc. 2008). The Univariate procedure was used to test the distribution of the data and the Means procedure was used to generate descriptive statistics. 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 $P < 0.1$ was used in this study.