4 WHELP CREEK SUB-WATERSHED

4.1 Introduction

4.1.1 Sub-watershed Description

The Whelp Creek (WHC) Sub-watershed is north of Red Deer and approximately 6 km west of the Town of Lacombe (Figure 4.1). The approximate centre of the watershed is at 52.43° N, 113.85° W. Its total drainage area is 5056 ha (50.56 km^2), or approximately 20 sections of land. This is a slightly larger value than previously reported (4595 ha) due to improved drainage information.

The WHC Sub-watershed lies in the Central Parkland Natural Sub-region, which is part of the Parkland Natural Region of the Alberta Natural Region classification. The 30-yr average (1971 to 2000) annual precipitation for Lacombe is 446 mm (Environment Canada 2013). The annual runoff for the WHC Sub-watershed is estimated to be approximately 38 mm (Bell 1994). The watershed is in the Black Soil Zone (Alberta Soil Information Centre 2013) and the soils are generally medium textured, including loam and silty loam. The soil types within the watershed include poorly drained soils (Alberta Soil Information Centre 2013) and there have been problems with water erosion in the watershed (Lacombe County 2007).

The Central Parkland Natural Sub-region, in which the study sub-watershed was located, has a gently rolling landscape and surficial deposits that range from intermediate textured hummocky and ground moraines to fine textured glaciolacustrine deposits and coarse outwash (Natural Regions Committee 2006). In the WHC Sub-watershed specifically, the topography is undulating with high-relief landforms (Figure 4.2). When divided into 20 smaller sub-watersheds, the slope of the land varies from 0.5 to 2.25%. The WHC Sub-watershed slopes downward from west to east, with an approximate 90-m difference in elevation between the lowest and highest points.

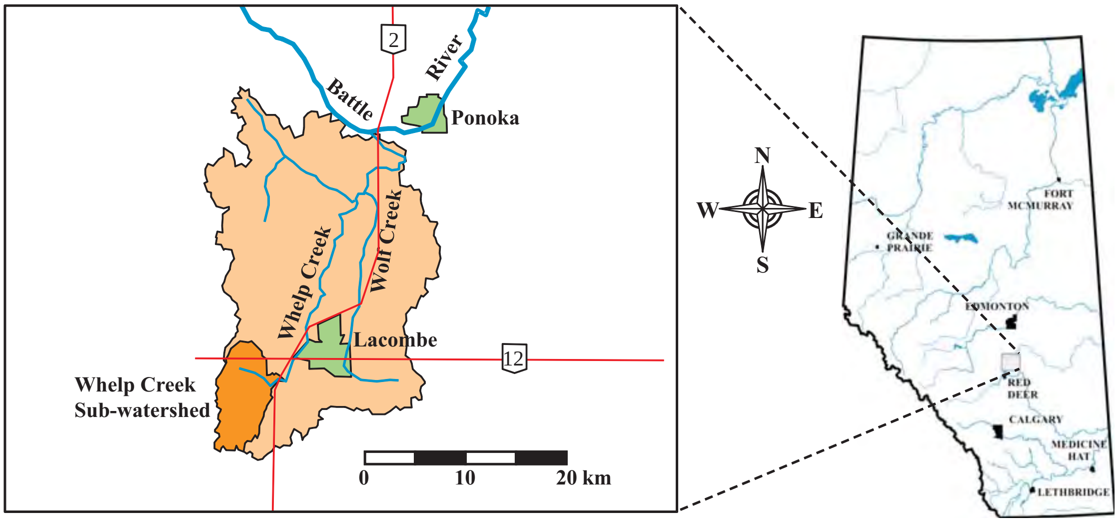

Figure 4.1. Location of the Whelp Creek Sub-watershed.

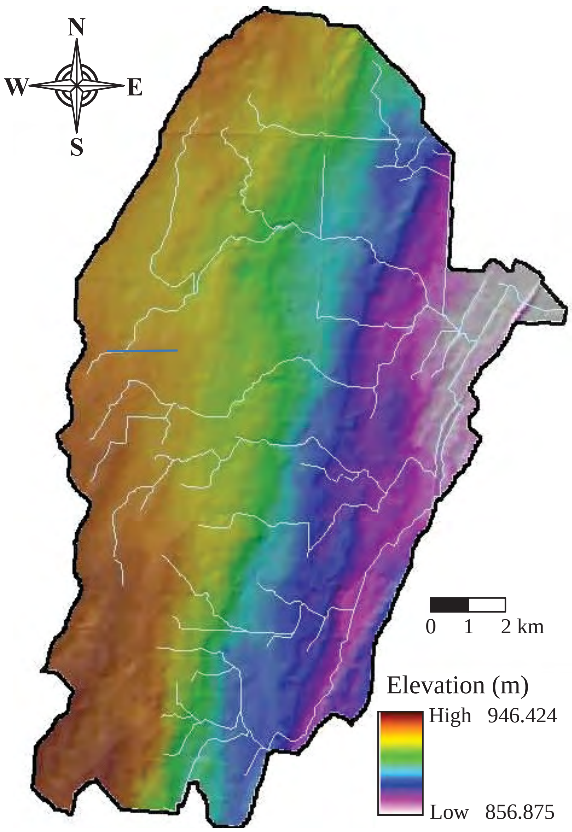

Figure 4.2. Topography and elevation of Whelp Creek Sub-watershed.

Whelp Creek (also known as Whelp Brook) flows from the northwest corner of the sub-watershed in a southerly direction, then turns and flows east until it is joined by the southern tributaries. The creek then crosses under Highway 2, which is the outlet of the sub-watershed (Figures 4.3). Beyond the WHC Sub-watershed, Whelp Creek continues to flow north and joins Wolf Creek (Figure 4.1). The distance from the sub-watershed outlet to the confluence with Wolf Creek is about 20 km. Wolf Creek flows north and empties into the Battle River near Ponoka, Alberta. Within the sub-watershed, Whelp Creek and its tributaries are small intermittent streams, which typically only flow from early spring to early summer after snowmelt or heavy rainfall events. Flow in the creek is also influenced by a shallow water table in the area. There are also several sloughs and other wetlands that dot the landscape in the sub-watershed. Unlike the Indianfarm Creek Watershed, which has incised channels, the stream beds in the WHC sub-watershed are usually undefined and shallow (Figure 4.4a). These characteristics, combined with the variability of the weather, enable producers to cultivate through portions of the creek and tributaries during some years (Figure 4.4b).

The primary land use in the sub-watershed is agriculture, with annual cereal cropping and livestock production being the major agricultural activities in the watershed. A large portion of the land is used for barley, canola, and wheat production. However, potato, corn, oat, rye, pea, and flax are also grown. In addition to cultivated crops, hay crops and pasture cover about 20 to 25% of land within the sub-watershed. Livestock production primarily includes dairy and beef operations. Hog operations that were active in the sub-watershed at the beginning of the study, but were no longer operating at the end. In addition to agriculture, the oil and gas sector is active in the area. Major future development is projected for the eastern half of the sub-watershed as it is zoned for industrial development.

4.1.2 Beneficial Management Practices Sites

Eight sites were established in the WHC Sub-watershed in 2008 (Figure 4.3). These included the West Field (WFD), North Field (NFD), East Field (EFD), South Field (SFD), North Pasture (NPS), and South Pasture (SPS) sites. In addition, two Reference (REF1 and REF2) sites were established. Pasture and cattle management was the focus at the two BMP pasture sites (NPS and SPS), while manure nutrient management was the focus at the other four BMP sites (WFD, NFD, EFD, and SFD).

4.2 Weather

4.2.1 Methods

Annual and 30-yr average (1971 to 2000) data were obtained for the nearby Environment Canada weather station at Lacombe CDA2 from AgroClimatic Information Services (ARD 2013b) (Sub-section 2.4.1). The Lacombe CDA2 weather station was outside of the WHC sub-watershed at a distance of about 7 km.

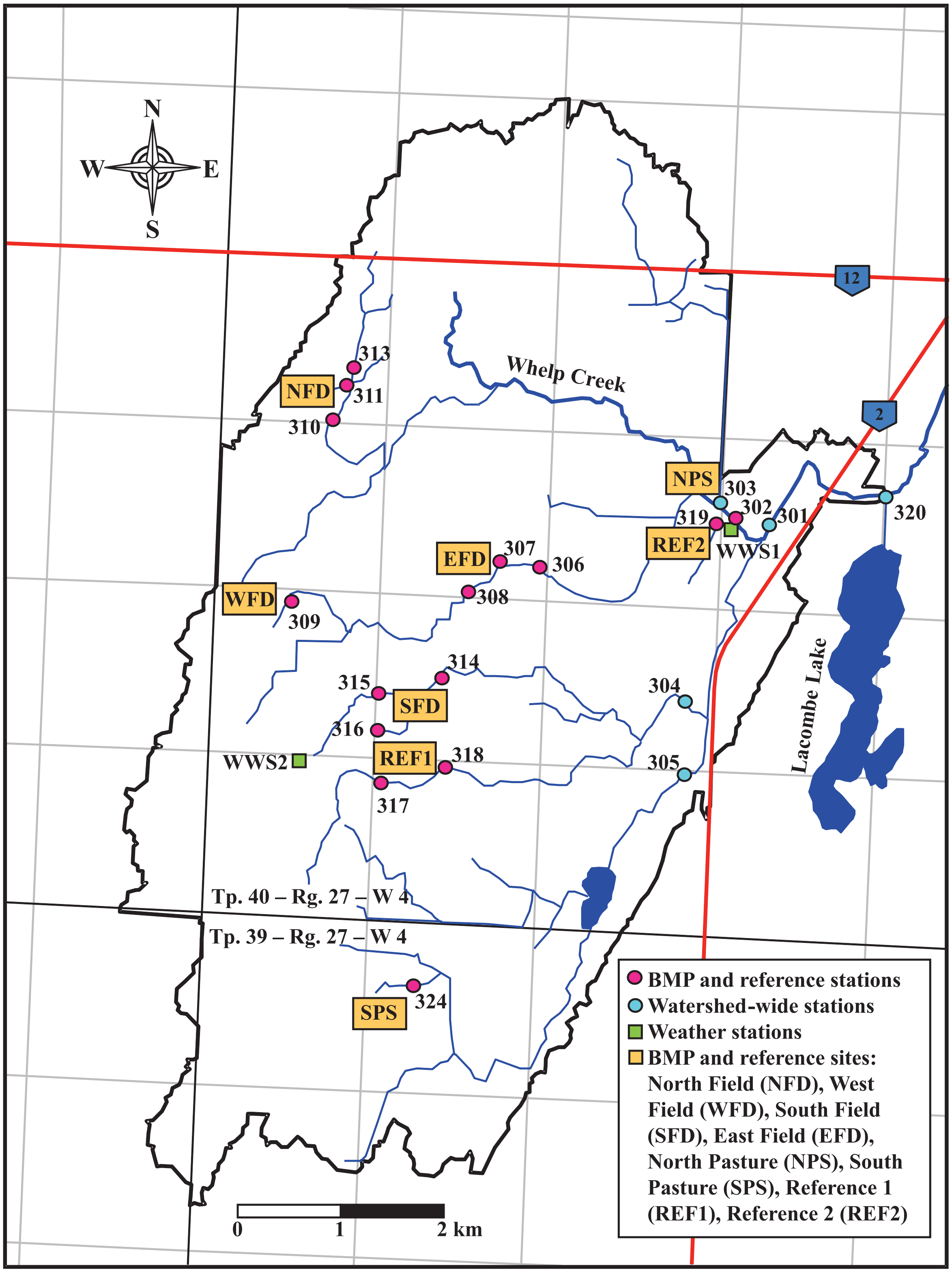

Figure 4.3. The Whelp Creek Sub-watershed showing the locations of the water monitoring stations, beneficial management practices sites, reference sites, and weather stations.

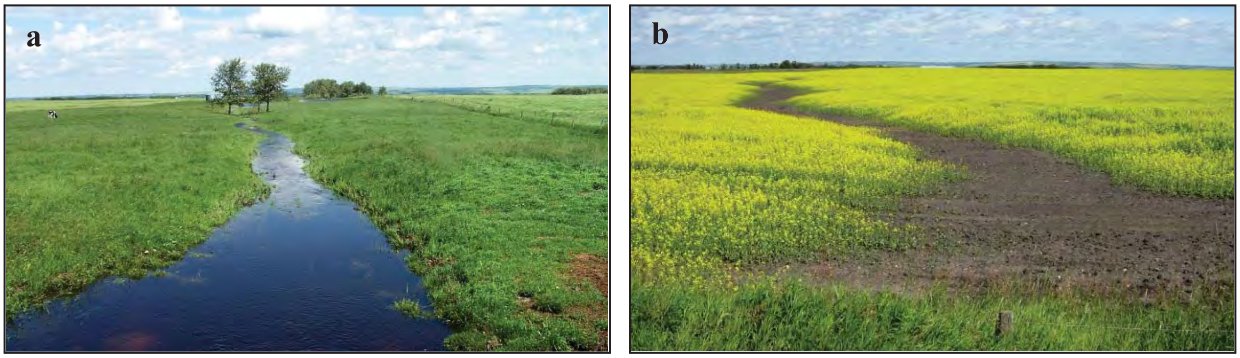

Figure 4.4. Views of (a) Whelp Creek in July 2010 and (b) a farmed-through tributary in July 2007.

To obtain site specific data, and to determine variability within the WHC sub-watershed, two automated weather stations were established in the sub-watershed in April and May 2008. The two stations were separated by a distance of 5.3 km. Whelp Creek Weather Station 1 (WWS1) was in the lower elevation area of the watershed near water monitoring Station 319 and WWS2 was in the higher elevation area and about 0.8 km west of water monitoring Station 317 (Figure 4.3). The watershed weather stations were removed in April (WWS2) and September (WWS1) 2012. Further description of the weather stations is in Sub-section 2.4.2.

4.2.2 Results and Discussion

The monthly average daily temperatures near the WHC Sub-watershed from 2007 to 2012 were generally consistent with 30-yr averages at the Lacombe CDA2 weather station (Table 4.1). The warmest year was 2007, with July having average daily temperatures that were the highest recorded during the project, and well above the 30-yr average. Overall, 2009 was the coldest year, with eight months having average daily temperatures less than the 30-yr averages. However, the growing season in 2009 was warmer than average, with June, July, and September having average daily temperatures higher than the 30-yr averages. The growing season with the coolest average temperature was observed in 2010.

The two driest years in WHC Sub-watershed were 2008 and 2009, which had 35 and 34% less total annual precipitation, respectively, than the 30-yr average (Table 4.2). Each month in 2008 had less precipitation than historical values, with the relative reduction in monthly precipitation that ranged from 2% in February to 81% in September. Nine months in 2009 had total precipitation less than the 30-yr averages, with April, May, June, and September being particularly dry. Total annual precipitation in 2012 was 11% less than the 30-yr average; whereas, total precipitation in 2007, 2010, and 2011 was 11 to 19% above the 30-yr average, with the greatest amount of precipitation in 2010. In these years, much of the above average precipitation occurred as rain from April to July (Table 4.2). Overall, the study period had 5 to 6% less precipitation than the 30-yr average, in terms of annual and growing-season precipitation respectively.

Table 4.1. Monthly, annual, and growing season average daily temperature from 2007 to 2012 and 30-yr (1971 to 2000) average values for the Lacombe CDA2 weather station (ARD 2013b).

Time period	2007	2008	2009	2010	2011	2012	2007-2012 average	30-yr average
	(°C)							
January	-8.2	-11.6	-11.1	-9.0	-11.8	-8.6	-10.0	-12.3
February	-10.9	-9.3	-10.5	-7.5	-12.7	-7.5	-9.7	-10.2
March	-1.7	-1.8	-8.2	0.8	-8.7	-1.6	-3.5	-3.8
April	2.3	1.2	3.1	5.1	1.6	4.1	2.9	4.3
May	9.9	10.9	9.0	7.9	10.6	9.6	9.7	10.1
June	14.8	13.4	13.2	13.6	13.3	14.3	13.8	13.9
July	19.4	15.6	16.2	15.5	15.3	17.7	16.6	15.4
August	13.1	15.6	14.4	14.1	15.3	16.4	14.8	14.7
September	8.9	9.8	13.3	8.1	12.5	12.1	10.8	9.8
October	5.0	4.6	0.8	5.6	4.2	0.9	3.5	4.5
November	-3.9	0.1	-0.4	-6.9	-5.1	-7.3	-3.9	-4.9
December	-10.7	-14.4	-16.1	-12.9	-5.1	-14.9	-12.3	-11.0
Annual (Jan to Dec)	3.2	2.8	2.0	2.9	2.5	2.9	2.7	2.5
Growing season (May to Sep)	13.2	13.1	13.2	11.8	13.4	14.0	13.1	12.8

Table 4.2. Total precipitation from 2007 to 2012 and 30-yr (1971 to 2000) average values for the Lacombe CDA2 weather station (ARD 2013b).

Time period	2007	2008	2009	2010	2011	2012	2007-2012 average	30-yr average
	(mm)							
January	6.5	4.6	12.8	5.8	38.4	5.7	12.3	17.5
February	17.3	10.6	6.2	1.1	9.7	6.4	8.6	10.8
March	3.1	4.7	10.9	1.2	31.3	23.6	12.5	12.8
April	45.9	15.0	9.0	40.8	14.6	42.1	27.9	21.0
May	118.7	47.4	14.0	97.3	42.2	60.6	63.4	55.6
June	161.9	55.8	31.0	111.8	81.5	95.2	89.5	75.7
July	43.6	49.8	92.7	168.5	183.1	62.9	100.1	89.4
August	58.7	56.0	61.8	32.2	55.7	30.0	49.1	70.8
September	42.3	8.8	8.8	47.8	4.6	15.0	21.2	47.3
October	10.5	13.5	19.7	6.7	6.6	19.3	12.7	16.6
November	6.0	9.0	6.2	15.4	19.6	17.5	12.3	14.0
December	2.2	13.4	22.1	3.2	8.3	17.4	11.1	14.5
Annual (Jan to Dec)	516.7	288.5	295.1	531.8	495.6	395.7	420.6	446.0
Growing season (May to Sep)	425.2	217.7	208.3	457.6	367.1	263.7	323.3	338.8

In terms of individual events, there was one particularly large rainfall (107 mm), which occurred on July 12 and 13, 2010 (Figure 4.5). Other precipitation events of note included 49 mm on June 17, 2007 and 52 mm on July 26, 2011. The greatest above average precipitation for a single month was for March 2011, which was 245% above average (Table 4.2).

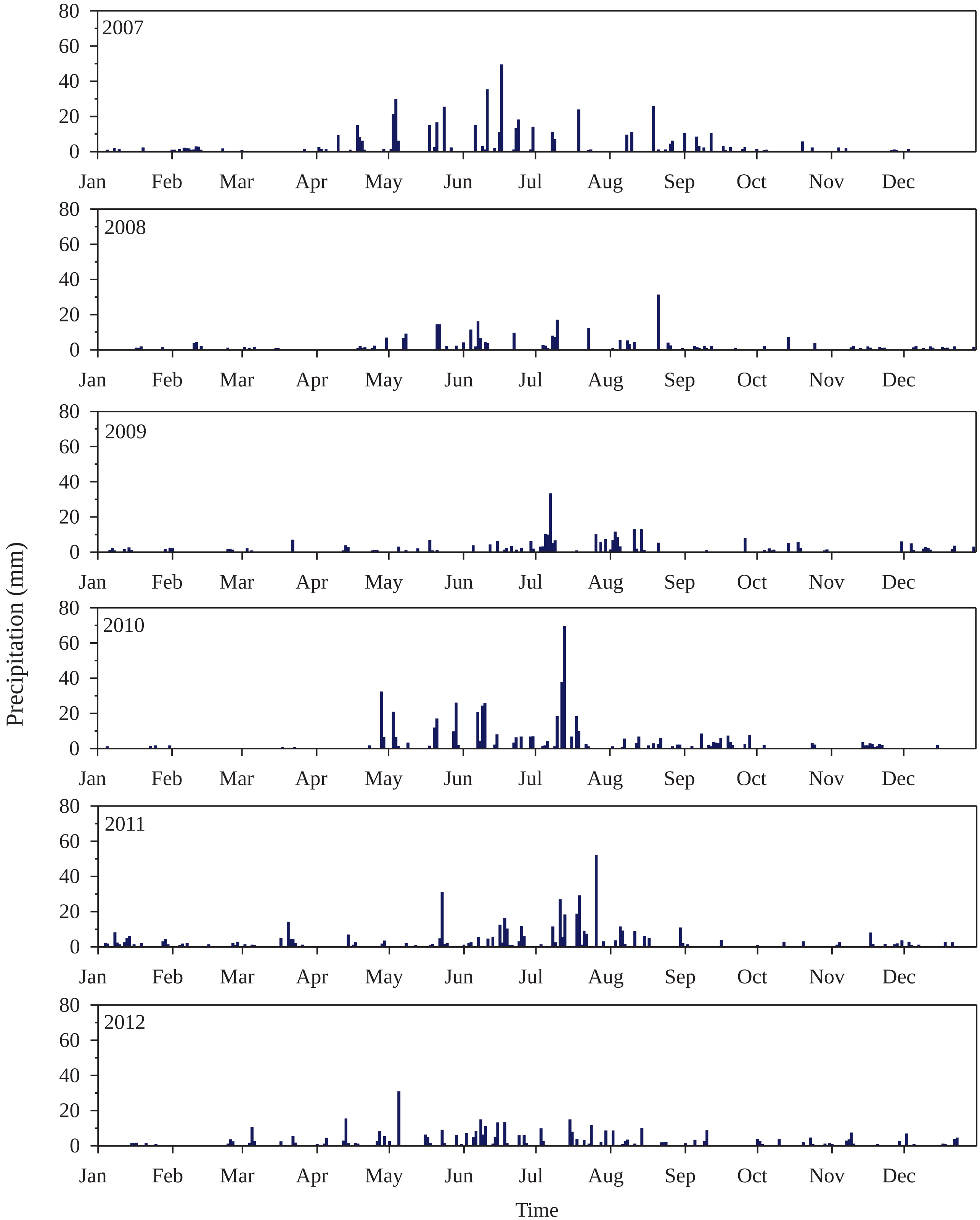

Figure 4.5. Total daily precipitation at the Lacombe CDA2 weather station from 2007 to 2012.

Average annual total precipitation from 2009 to 2011 was similar among the two weather stations installed in the sub-watershed. The 3-yr average was 501 ± 142 mm (average ± standard deviation) at WWS1 and 531 ± 155 mm at WWS2. Because precipitation was only measured for a portion of the year in 2008 and 2012 at the two watershed stations, these data were not included in the average values.

Average annual total precipitation recorded at the two sub-watershed weather stations was greater than at the Environment Canada Lacombe CDA2 station (Figure 4.6). The difference was greatest in 2011, when the average precipitation was 23% greater at the sub-watershed weather stations compared to Lacombe weather station, and least in 2010, when the sub-watershed weather stations recorded 10% more precipitation than the Lacombe station. Therefore, certain exercises, such as hydrological modelling, may benefit from weather data collected within the sub-watershed.

The duration of the pre- and post-BMP periods varied among the BMP sites (Section 2, Figure 2.2). Generally, 2008 to 2009 was considered predominately the pre-BMP period and 2010 to 2012 was considered predominately the post-BMP period. The average annual temperature was 2.4°C for the pre-BMP period and 2.8°C for the post-BMP period, compared to 2.5°C for the 30-yr average (Table 4.1). In terms of total precipitation, the pre-BMP period (291.8 mm) was well below the 30-yr average (446.0 mm); whereas, the post-BMP period (474.4 mm) was above the 30-yr average (Table 4.2).

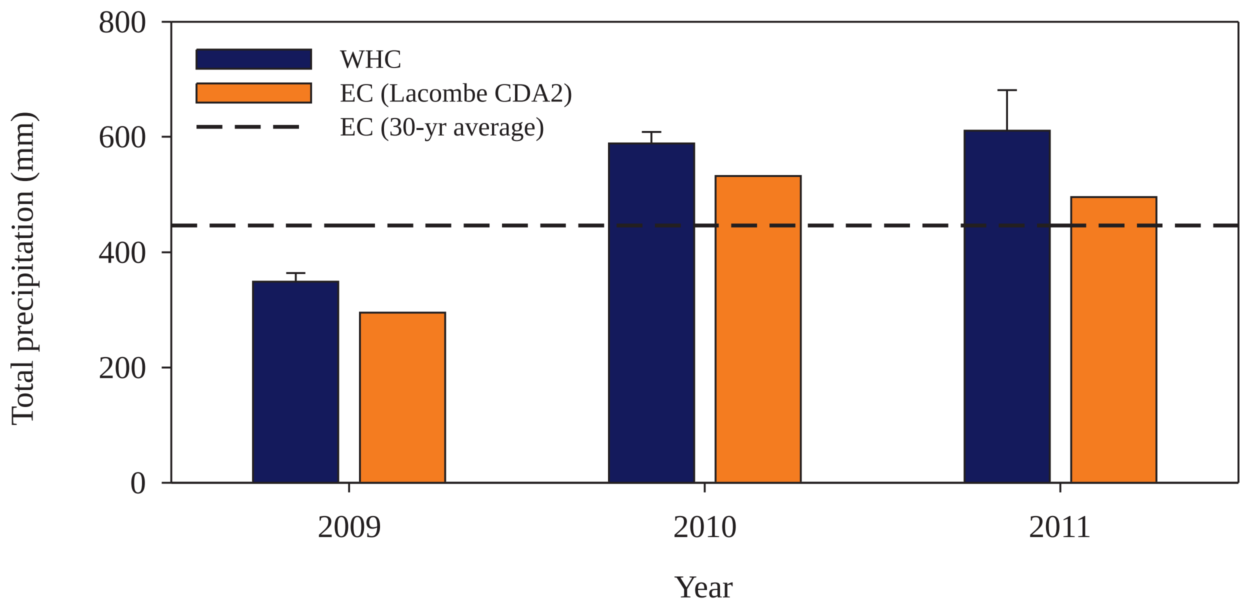

Figure 4.6. Average total precipitation of the Whelp Creek (WHC) weather stations (n = 2) compared to the Environment Canada (EC) Lacombe CDA2 weather station from 2009 to 2011. The stations were not operational in 2007 and data were collected for only a portion of 2008 and 2012. The T-bars for the WHC data are standard deviations.

4.3 Land Use and Land Cover

4.3.1 Methods

Annual land cover and land use information in the WHC Sub-watershed were recorded during driving surveys using AgCapture software. These surveys were conducted on August 8 and 9, 2007; September 3 and 4, 2008; August 11 and 12, 2009; August 18 and 19, 2010; August 22 and 23, 2011; and August 13 and 14, 2012. Survey results were compared and verified with land-cover information from previous years, along with ongoing field visits and producer feedback. The resulting AgCapture database was used to create land-use maps for the sub-watershed. Since the distribution of land use was similar among the study years, only the 2012 maps are presented. Details about AgCapture and history of the software are reported in Subsection 2.5.1.

4.3.2 Results and Discussion

The total area of the WHC Sub-watershed was 5056 ha, and in 2007, included approximately 60 landowners with 50 active producers. From 2008 to 2012, agricultural land accounted for approximately 86.7% of the land surveyed in the sub-watershed (Table 4.3). The major agricultural land uses included annual crops (62.3%) perennial crops (22.7%), and farmyards (1.6%). In 2008, the agricultural land percentage was slightly lower than in subsequent years, but this could be attributable to the fact that in that year, 1.3% of the area was not surveyed, as it was not accessible. Additionally, in 2009, watershed boundary adjustments were made. This caused minor changes in land-cover percentages, and may or may not have contributed to the lower percentage of land occupied by agriculture observed in 2008. The percentages of different types of agricultural land use stayed relatively consistent with time (Table 4.3). However, there was a slight decrease in annual crop cover and an increase in perennial crop cover in 2009 as compared to previous years. However, this was reversed in 2012. In addition to agricultural production, natural areas (forest, grassland, water bodies, and wetlands) comprised 9.2% of the sub-watershed, and other non-agriculture land uses (residential, commercial, industrial, transportation, and idle land) covered 3.8%.

The major annual crops in the WHC Sub-watershed included barley (*Hordeum vulgare*) (24.1%), canola (*Brassica napus*) (20.3%), wheat (*Triticum aestivum*) (11.2%), corn (*Zea mays*) (4.0%), potato (*Solanum tuberosum*) (1.0%), and to a lesser extent, oat (*Avena sativa*), rye (*Secale cereale*), pea (*Pisum sativum*), flax (*Linum usitatissimum*), and fallow (Table 4.3; Figure 4.7). There was a large increase in barley production in 2010 compared to 2009 (+7.6%), and a simultaneous decrease in wheat production (-12.2%).This was likely a result of a misclassification of wheat for barley during this survey. However, commodity prices may have had an influence on crop production and could have contributed to this change. There were also fluctuations in canola production during the study, with the largest increase in 2012 (+7.3%) as compared to 2011 (Table 4.3). This was mirrored by decreases in barley (-2.8%) and wheat production (-3.8%). While these trends reflected commodity prices, crop rotation could also have contributed to inter-annual variation in crop cover. Vegetation cover for perennial species was much less dominant, and included pasture (8.8%) and hay varieties (14.3%) (Figure 4.8).

The WHC Sub-watershed had significant livestock production, which was dominated by confined feeding operations, most of which were dairies, and to a lesser extent beef feedlots (Figure 4.9). There was also a small component of pasture and grazing of non-confined livestock. Based on estimations in 2008, there were approximately 2159 cows (1879 dairy and 280 on pasture) and 481 calves in the WHC Sub-watershed. There were also three hog operations active in the watershed, but these were no longer operating by 2009.

Although some changes in land use and land cover have been described, the proportion of different land uses within the sub-watershed remained fairly similar among the 5 yr of the study. Small differences were mostly attributable to changes in land-cover classification types and a few errors associated with identifying land cover.

Table 4.3. Percent cover of land-use practices in the Whelp Creek Sub-watershed from 2008 to 2012.

Land use practice	2008	2009	2010	2011	2012	Average
Barley	23.6	23.6	31.2	22.4	19.6	24.1
Canola	23.7	16.9	18.8	17.5	24.8	20.3
Corn	2.7	3.1	3.5	5.4	5.4	4.0
Fallow	1.1	0.4	1.3	0.1	1.1	0.8
Flax	0	0	0	0	0.5	0.1
Oat	0.2	0.8	1.1	0.5	0	0.5
Pea	0	0	0	0	0.6	0.1
Potato	0.9	0.9	0.5	1.5	1.2	1.0
Rye	0	0	0.8	0	0	0.2
Wheat	10.8	16.1	3.9	14.4	10.6	11.2
Unknown	0	0	0	0	0.2	0.04
Annual crops total	**63.0**	**61.8**	**61.1**	**61.8**	**64.0**	**62.3**
Hay - grass	2.2	1.8	3.3	4.1	2.6	2.8
Hay - legume	5.0	7.9	8.6	8.3	6.1	7.2
Hay - mixed	5.3	4.4	3.6	3.5	5.0	4.4
Hay total	**12.5**	**14.1**	**15.5**	**15.9**	**13.7**	**14.3**
Pasture	7.6	9.7	9.0	7.8	7.9	8.8
Perennial crops total	**20.1**	**23.8**	**24.5**	**23.7**	**21.6**	**22.7**
Farmyards[z]	1.7	1.6	1.7	1.6	1.6	1.6
Agriculture total	**84.8**	**87.2**	**87.3**	**87.1**	**87.2**	**86.7**
Idle	0.0	0.0	0.03	0.03	0.03	0.02
Commercial	0.3	0.2	0.2	0.2	0.2	0.2
Industrial	0.2	0.1	0.1	0.1	0.1	0.1
Natural areas	8.8	9.2	9.2	9.4	9.2	9.2
Residential[y]	1.3	0.1	0.02	0.02	0.02	0.3
Transportation	3.2	3.2	3.2	3.2	3.2	3.2
Other land use total	**13.8**	**12.8**	**12.8**	**13.0**	**12.8**	**13.0**
Not surveyed	1.3	0	0	0	0	0.3

[z] Includes greenhouses and potato storage.
[y] In 2009 and 2010, much of the residential areas were classified as natural areas. Residential areas were classified as natural grass to satisfy the modelling component. In the model, residential assumes pavement/gravel so this would give a much different runoff coefficient.

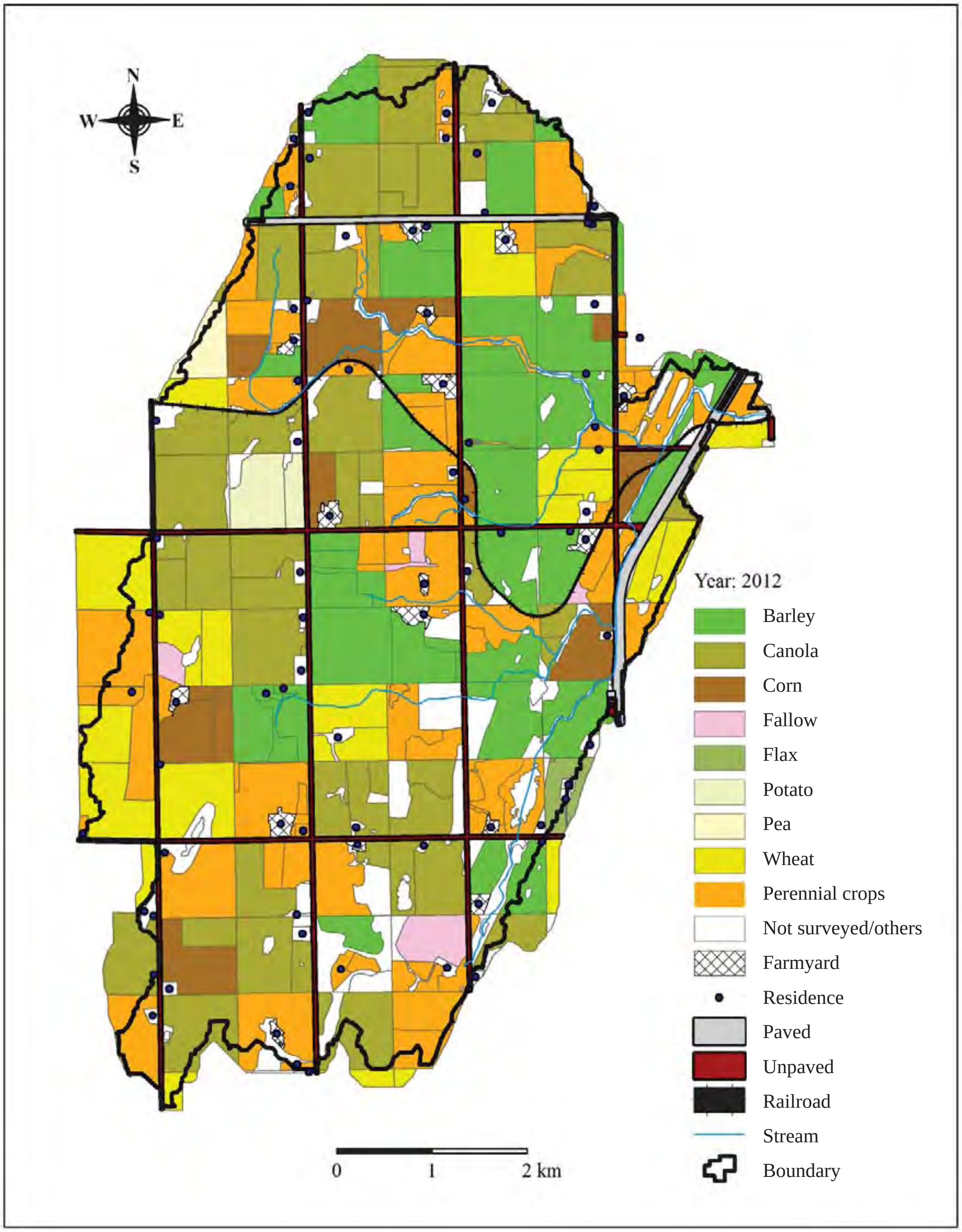

Figure 4.7. Annual crop distribution and types in the Whelp Creek Sub-watershed in 2012.

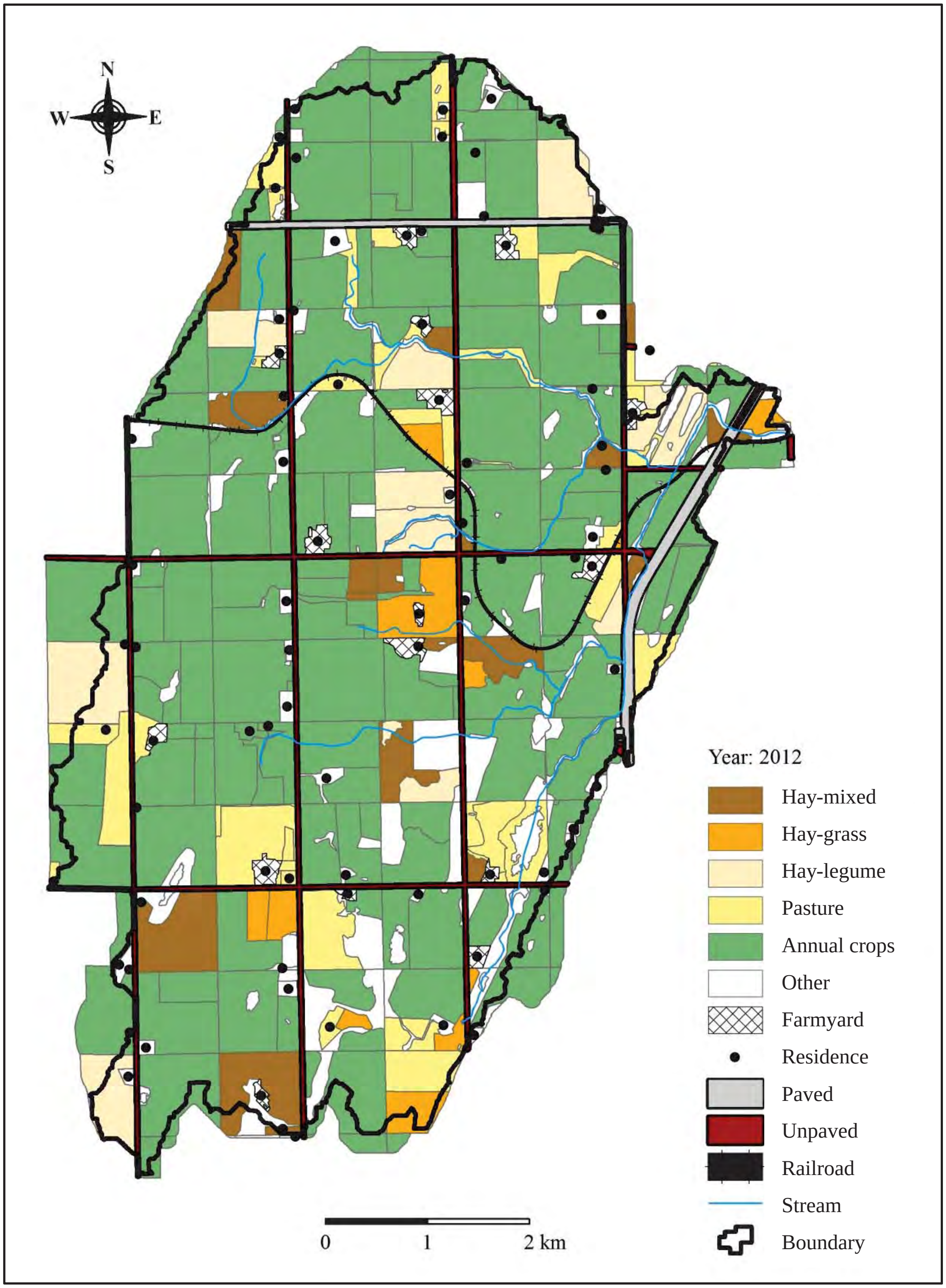

Figure 4.8. Perennial crop distribution and types in the Whelp Creek Sub-watershed in 2012.

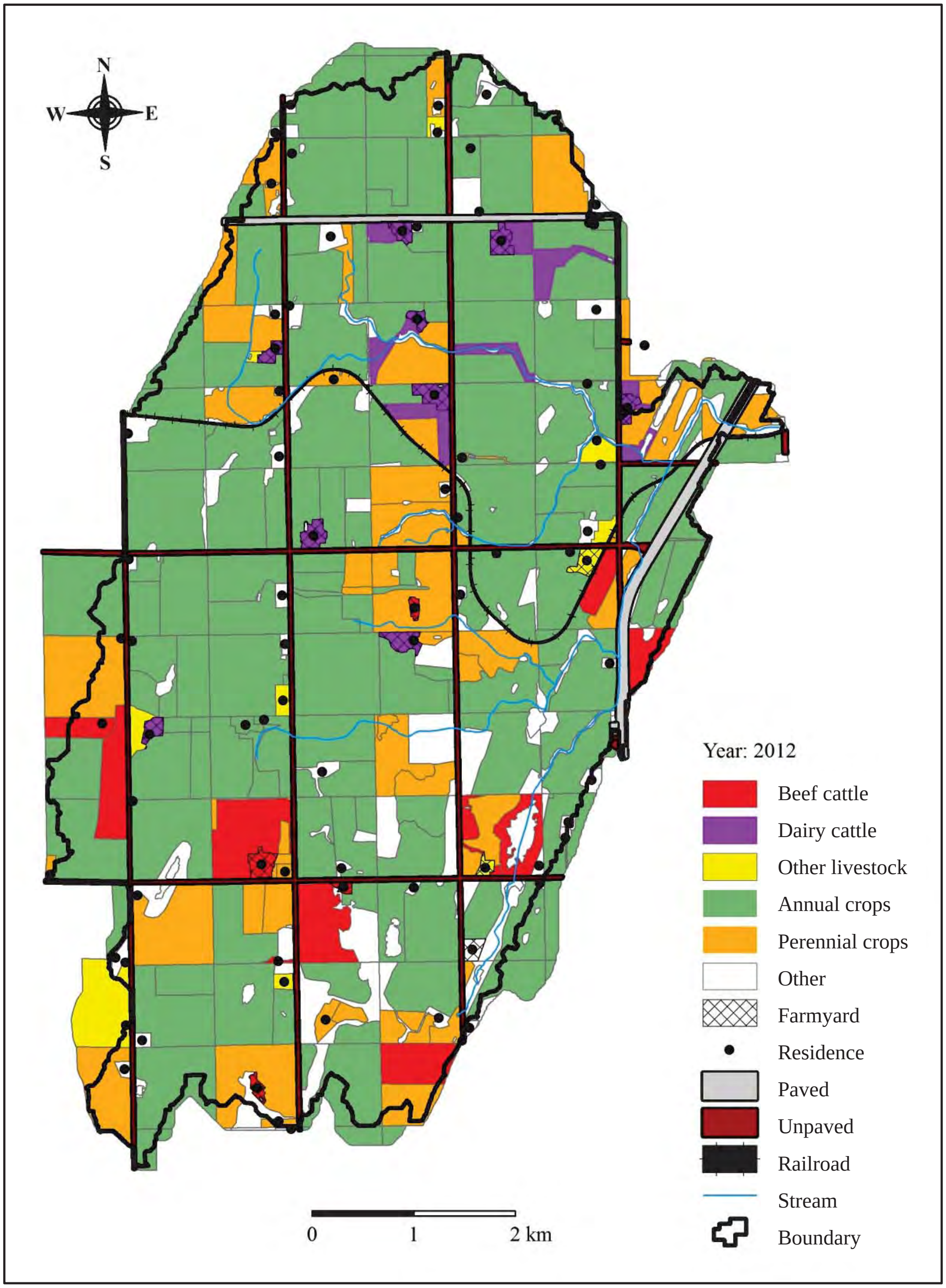

Figure 4.9. Livestock distribution in the Whelp Creek Sub-watershed in 2012.

4.4 Watershed Surface Hydrology and Quality

Four watershed-wide sites and an edge-of-field site near the outlet in the WHC Sub-watershed were sampled from 2008 to 2012 for watershed-wide assessment. Data from these samples were used to characterize the overall water quality and quantity, and for the assessment of how water quality changed from the headwaters to the outlet of the sub-watershed. In April 2009 and April 2011, low-flow and high-flow, respectively, synoptic surveys were completed along the mainstem and tributary. The objectives of the WHC watershed-wide assessments and synoptic surveys were to:

- Characterize the watershed in terms of hydrology and water quality during snowmelt and rainfall;
- Determine tributary water quality and quantity contributions to the outlet; and
- Track a parcel of water to assess changes in water quality (synoptic survey).

4.4.1 Methods

4.4.1.1 Watershed-wide Assessment

Four watershed-wide stations (301, 303, 304, and 305) and an edge-of-field station near the outlet (319) were sampled from 2008 to 2012 (Figure 4.10). Station 301 was used as the watershed outlet and Station 303 was on the mainstem upstream of the outlet. Stations 304 and 305 each represented a southern tributary in the sub-watershed. Station 305 was located downstream of a large wetland and flow at this station was dependent on overflow from the wetland. Station 319 (Sub-section 4.13) was near the outlet and flow from this site was from groundwater discharge and surface runoff that entered the mainstem between Stations 303 and 301. Stations 303, 304, and 305 were grab sampled while Stations 301 and 319 were either grab or Isco sampled. Grab samples were taken at Stations 301 and 319 when the Isco samplers could not operate due to cold weather or were not activated. Stations 303 and 319 were also used as BMP evaluation stations.

Further details about water sampling, water analysis, and data analysis are in Sub-section 2.8. Most samples were collected during snowmelt or rainfall events during the study. For example, 34 snowmelt and 62 rainfall runoff event samples were collected at the outlet (Station 301). A few base-flow samples were collected at the end of rainfall runoff events in 2008, 2010, 2011, and 2012. However, base-flow samples were grouped with rainfall samples because the water chemistry was similar between the two event types and there were very few true base-flow samples collected.

Other aspects of the watershed-wide analysis included the calculation of flow-weighted mean concentrations (FWMC) at the outlet and mass loads of nutrients and total suspended solids (TSS) (Sub-section 2.8.4). These parameters were compared to the Alberta Environmental Sustainable Agriculture (AESA) Water Quality Program watersheds (Lorenz et al. 2008). The Nutrient Water Quality Sub-index (NWQS-I) (Sub-section 3.4.1.1) was also used to compare relative water quality among sites and among years. Only the in-stream Stations 301, 303, 304, and 305, and not the

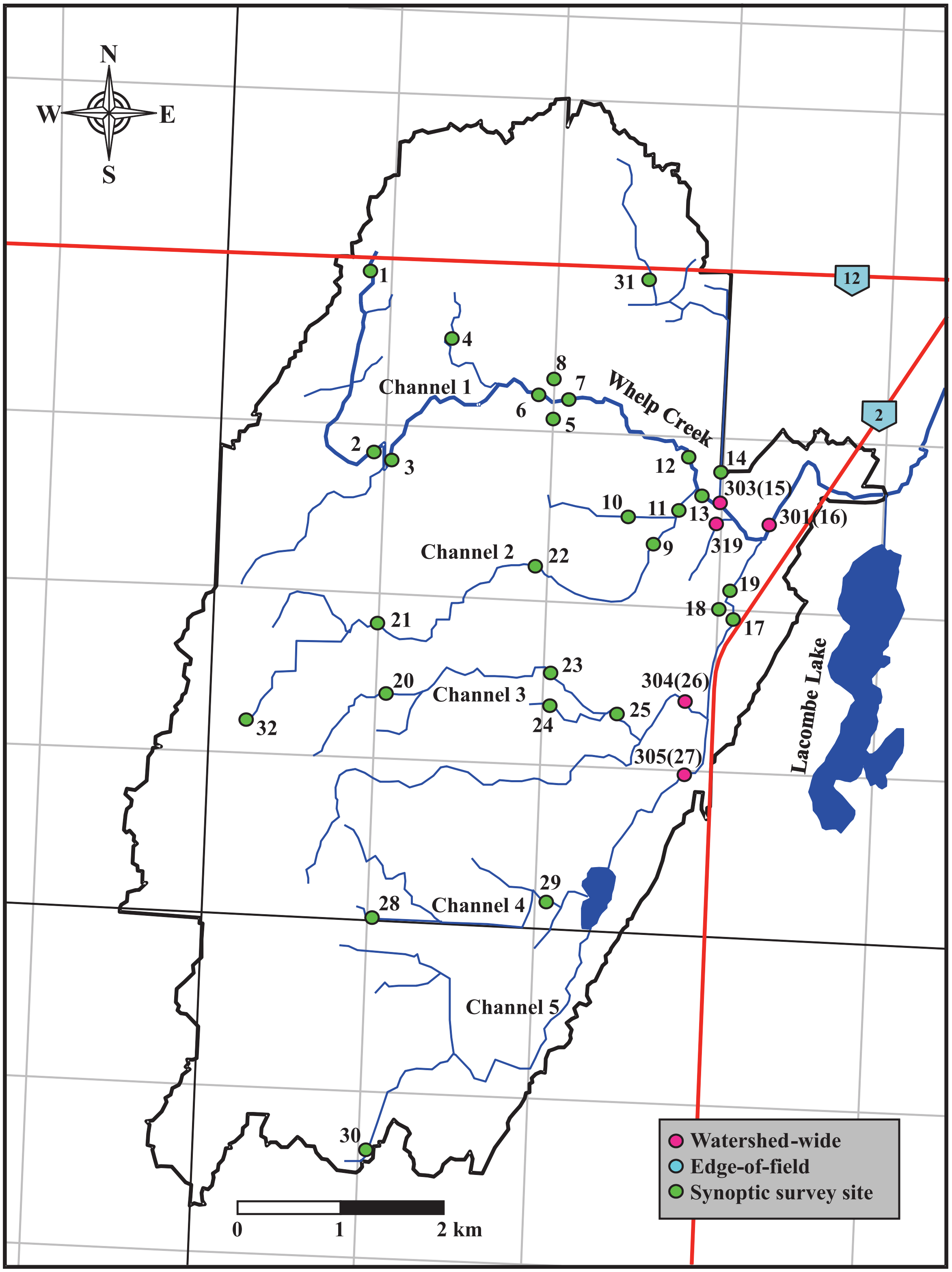

Figure 4.10. Watershed-wide and synoptic survey sampling sites for the Whelp Creek Sub-watershed.

edge-of-field Station 319, were used for the NWQS-I assessment. Regression analysis between flow and water quality parameter concentrations was carried out for the sub-watershed outlet. Parameter concentration values for individual water samples and the associated average flow (m^3 s^{-1}) corresponding to each water sample were used in the regression analyses. Regression analysis was also carried out between annual flow and mass loads of nutrients and TSS.

4.4.1.2 Synoptic Survey

Synoptic surveys were completed in April 2009 and 2011. Both synoptic surveys were carried out during the snowmelt periods. In 2009, the synoptic survey was completed on April 15. In 2011, the synoptic survey was carried out in two days. The first day, April 19, focused on the mainstem, while the second day, April 20, focused on one the main tributaries south of the mainstem. In relative comparison to each other, the 2009 survey was consider low flow and the 2011 survey was considered high flow. A synoptic survey is the technique of tracking and sampling a single parcel of water as it moves downstream. Further information on synoptic survey objectives and methods are in Sub-section 3.4.1.2.

In early 2009, 32 sites in the WHC Sub-watershed were selected for the synoptic surveys along the mainstem and tributaries. Sites were selected and labeled numerically (Figure 4.10; Table 4.4). Four of the watershed-wide stations also served as synoptic sites: Station 301 (Synoptic Site 16), Station 303 (Synoptic Site 15), Station 304 (Synoptic Site 26), and Station 305 (Synoptic Site 27). Sites were selected to determine how smaller tributary and ditch contributions affected surface water quality of the mainstem and the larger tributaries. Sites were placed upstream and downstream of the smaller tributary outlets. Although downstream sites were placed to allow for an adequate mixing zone, pooled water often required moving the sampling site such that samples would be taken from free-flowing water.

In 2009, each site with flow was grab sampled (Sub-section 2.8.2) once during the 1-d survey. In 2011, most sites were grab sampled once, except for three mainstem sites that were sampled twice, once on each day. Site 16 (outlet) was sampled on Days 1 and 2, as well as mainstem Sites 12 and 13, which were the upstream and downstream sites, respectively, relative to tributary Site 11 (Figure 4.10). Due to no flow and non-connective flow, not all of the southern tributaries were sampled during both surveys. In 2009, only the Site 19 southern tributary system was sampled. In 2011, only the Site 11 southern tributary system was sampled. Water samples were analyzed as described in Sub-section 2.8.3.

Flow was measured at all synoptic survey sites. In 2009, the majority of the sites had too little flow to use the Swoffer (Sub-section 2.7.5). Flow was measured with the Swoffer at Sites 13, 14, 15, and an Argonaut was used at Site 16. When the Swoffer could not be used, flow was estimated using a stopwatch and a 1-L container. In 2011, flow was greater than in 2009 and flow was measured with a FlowTracker (Sub-section 2.7.5).

Water parcel travel times were estimated using the Soil and Water Assessment Tool (SWAT; version 6.3.10). The SWAT model required the input of the channel length and slope of each site. Slope was determined using 5-m grid digital elevation model data. The estimated flow velocity and water parcel travel times were determined as described in Sub-section 3.4.1.2.

4.4.1.3 Streambed Sediment Sampling

Streambed sediment samples were collected at 18 synoptic survey sites in spring 2009. In addition, sediment samples were collected at two BMP monitoring stations (Stations 310 and 313). Sediment samples were not collected during the 2011 synoptic survey. Sediment samples were collected on June 4, 2009 and the methodology used was the same as used for the Indianfarm Creek Watershed sediment sampling and analysis in 2008 (Sub-section 3.4.1.3). For comparison purposes, the 20 sampling sites were grouped into five land-cover types: cropped (Station 310 and Site 24), forested (Sites 6, 11, 12, 14, 21, 22), grassed (Station 313 and Sites 5, 8, 23, 25, and 26), grazed (Sites 7 and 15), and wetland (Sites 3, 13, 16, and 19). A linear regression analysis was carried out between degree of phosphorus sorption (DPS) of sediment samples and total dissolved phosphorus (TDP) in water. Total dissolved P concentrations from the 2009 synoptic survey were used for the sediment samples collected at synoptic survey sites. Total dissolved P concentrations for Stations 310 and 313 were obtained from water samples collected on April 13 and April 12, respectively, in 2009.

Table 4.4. Whelp Creek Sub-watershed synoptic survey sites. Distances (km) downstream are shown in parentheses.

Channel 1[z]	Channel 2	Channel 3	Channel 4	Channel 5[y]
1 (0)[x]	32 (0)[u]	20 (0)	28 (0)	30
2 (2.9)	**21** (2.5)	23 (2.0)	29 (2.0)	27
3 (3.2)[w]	**22** (4.6)	24 (T)		
4 (T)	**9** (6.4)	25 (2.9)		
5 (T)	**10** (T)	26 (4.2)[v]		
6 (5.5)	**11** (6.8)	17 (5.6)		
7 (5.5)		18 (T)		
8 (T)		19 (5.8)		
12 (7.2)				
13 (7.7)				
31 (T)				
14 (T)				
15 (7.8)				
16 (8.6)				

[z] Smaller tributaries and ditches are indicated by a (T).
[y] Distances are not shown because a large wetland was between these two sites. Due to the wetland, travel times were irrelevant; however, Synoptic Site 27 was grab sampled at the same time as Synoptic Site 26 in 2009.
[x] Numbers in bold indicate sites that were sampled only in 2011.
[w] Numbers in bold and underlined indicate sites that were sampled in 2009 and 2011.
[v] Numbers underlined indicate sites that were sampled only in 2009.
[u] Numbers not bold or underlined were not sampled in 2009 or 2011.

4.4.2 Results and Discussion

4.4.2.1 Sub-watershed Outlet (Station 301)

Sub-watershed outlet flow. During the 5-yr study, the lowest annual flow was in 2009 and the highest annual flow was in 2011 (Table 4.5) at the outlet. Smaller annual flows occurred from 2008 to 2010 compared to the higher flows in 2011 and 2012. The flow was more than 230-fold greater in 2011 compared to 2009. There was 200 mm more precipitation in 2011 than in 2009. However, 2009 was not the driest year and 2011 was not the wettest year during the study period (Table 4.2). The driest year was 2008 and the wettest year was 2010, and this likely contributed to the difference in annual flows between 2009 and 2011. The even drier conditions in 2008 likely resulted in low soil moisture in 2009. Low soil moisture along with less-than-average precipitation in 2009 would have favoured infiltration rather than runoff. Similarly, even though the highest precipitation was in 2010, the previous two years were much drier, resulting in less annual flow in 2010 compared to 2011 and 2012. Soil profiles and shallow groundwater were likely recharged in 2010. Possibly higher antecedent soil moisture in 2011, along with greater-than average precipitation, may have caused the largest annual flow observed during the study. We hypothesize that in the WHC Sub-watershed previous precipitation amounts likely affect soil moisture and groundwater recharge, which in turn can also influence runoff and annual flow, along with current precipitation, in a given year.

The relative contributions of snowmelt and rainfall to annual flow were extreme in 2009 and 2010 at the outlet. In 2009, all of the annual flow occurred during snowmelt; whereas, no flow occurred during snowmelt in 2010 (Table 4.5). The contributions during snowmelt and rainfall were more evenly distributed in the other years. On average, 45% of annual flow occurred during snowmelt events at the outlet of the sub-watershed.

Table 4.5. Annual total precipitation and annual flow at the outlet of Whelp Creek Sub-watershed (Station 301) from 2008 to 2012.

			Event-based distribution of flow	
Year	Total precipitation[z] (mm)	Annual flow ($m^3\ yr^{-1}$)	Snowmelt (%)	Rainfall/base flow (%)
2008	288.5	355,999	42	58
2009	295.1	25,319	100	0
2010	531.8	644,966	0	100
2011	495.6	5,896,213	46	54
2012	395.7	1,686,658	39	61
Average	401.3	1,721,831	45	55

[z] Precipitation at the Lacombe CDA2 weather station (ARD 2013b).

Flow typically began in April at the outlet and generally continued into the spring and/or summer (Figure 4.11a). In 2010, flow started in June and ended in July. The shortest flow period was in 2009, with flow only in April. The longest period of flow was from April to November 2011, with particularly high flows in April and July. The largest peak flows observed were 3.7 $m^3 s^{-1}$ on April 25, 2011 during snowmelt and 3.7 $m^3 s^{-1}$ on July 26, 2011 during rainfall. The peak flow during snowmelt at the WHC sub-watershed outlet was comparable to the IFC Watershed, which had a peak flow of 4.6 $m^3 s^{-1}$ on March 15, 2011. However, the maximum peak flow during rainfall at the WHC Sub-watershed outlet was much less than the 80 $m^3 s^{-1}$ peak flow observed at the outlet of the IFC Watershed in 2010 (Sub-section 3.4.2.1).

A water balance determined for the outlet (Station 301) showed that in some years the annual flows at Stations 303, 304, 305, and 319 accounted for nearly all the flow at the outlet (2010 and 2012) while in other years (2009 and 2011) this was not the case (Table 4.6). In 2010, the sum of the flows for these four stations was 71% greater than at Station 301; whereas, in 2012, the four watershed-wide stations accounted for only 73% of the flow at the Station 301. The flow at Station 303, which was on the mainstem and a short distance from the outlet (Figure 4.10), was 78 and 62% of the flow at Station 301 in 2010 and 2012, respectively. Observations in 2010 and other years showed that in addition to the flow from the mainstem, a portion of flow at Station 303

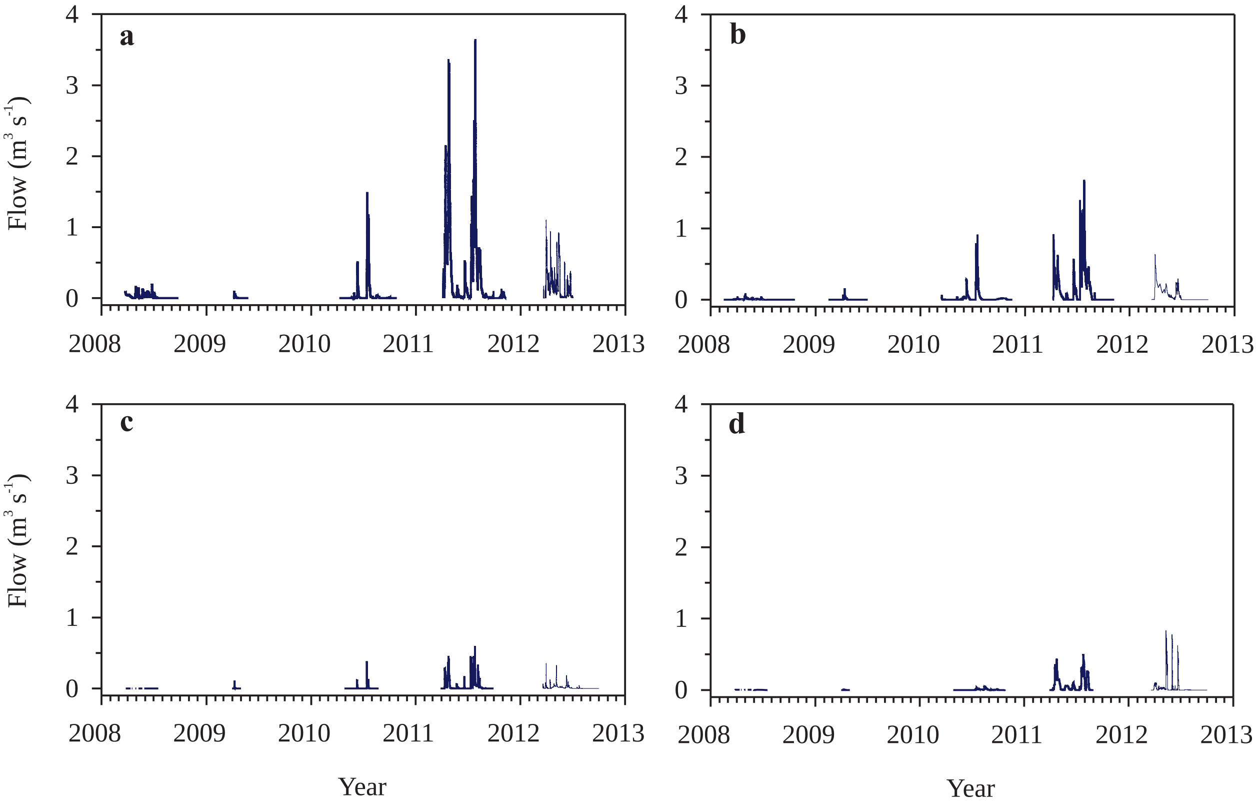

Figure 4.11. Flow measured at the Whelp Creek (a) outlet (Station 301), (b) Station 303, (c) Station 304, and (d) Station 305 from 2008 to 2012. Note the different y-axis scale in figure (a).

originated from a northern tributary that was diverted into a ditch (Figure 4.12). Typically in a given year, the mainstem upstream from Station 303 contributed more to the outlet than the southern tributaries (Station 304 and 305). However, in 2008 it appeared the majority of the flow at Station 301 may have originated from Stations 304 and 305, as only 29% of the flow at Station 301 was accounted for by Stations 303 and 319. In all years, the flow at Station 319 represented a small (1 to 4%) portion of the flow at Station 301.

Table 4.6. Annual Flow for each major tributary and the outlet (Station 301) of Whelp Creek Sub-watershed from 2008 to 2012.

	2008	2009	2010	2011	2012
Station	------------------------		(m^3 yr^{-1})		------------------------
301	355,999	25,319	644,966	5,896,213	1,686,658
303	89,333	31,871	500,222	2,601,816	1,045,549
304	na[z]	6,986	58,211	668,794	234,895
305	na[z]	3,547	66,819	969,338	534,380
319	12,992	980	26,176	57,766	19,433
Sum of 303 to 319	na	43,384	651,428	4,297,714	1,834,257
Percent difference from 301	na	171	101	73	109

[z] na = not available. Stations 304 and 305 were not equipped with float potentiometers until fall 2008.

Figure 4.12. Station 303 was often influenced by water flowing through a road ditch from the north (top) and into the mainstem (flow from the left). Station 303 was located at the downstream end of this culvert (to the right). Image was taken June 12, 2010.

Similar to the outlet, the annual flows at the other four stations were smallest in 2009 (Figure 4.11; Table 4.6). In 2009, the annual flow at Station 303 was 26% greater than at Station 301. Drier conditions in 2008 and 2009 resulted in low flow in 2009 because of the lack of snowmelt flow connectivity and the absence of rainfall runoff. Furthermore, a marsh area was between Stations 301 and 303, and may have acted as a sink for runoff water during low flows, attenuating the flow from Station 303 to Station 301. As a result, particularly in 2009, water sampled at Station 301 was not always representative of the whole watershed because of non-connective flow. In contrast, annual flow was greater at the outlet compared to the combined flow values from the four watershed-wide stations in 2011. In high-flow years, as in 2011, runoff water from sources upstream from Station 301 but downstream from Stations 303, 304, and 305, such as ditchwater and runoff from lands to the northeast and southeast, may have contributed to the increased flow at the outlet. It would appear that a net water balance of zero between the outlet stations and the other four watershed-wide stations was obtained in years of moderate flow (2010 and 2012). However, in years of lower or higher flow, a zero water balance was not achieved, likely caused by non-connective flow in low-flow years (2009) or unaccounted flow in high-flow years (2011).

Sub-watershed outlet water quality. The average (all years) concentrations of total nitrogen (TN), organic nitrogen (ON), nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), total phosphorus (TP), TDP, and particulate phosphorus (PP) were highest during snowmelt runoff at the outlet (Table 4.7). For example, TN concentration was 1.7-fold and TP concentration was 1.5-fold greater during snowmelt events compared to rainfall events. In contrast, the average concentrations of TSS, chloride (Cl), *Escherichia coli* (*E. coli*), electrical conductivity (EC), and pH were lower during snowmelt events compared to rainfall events (Table 4.8). The highest average concentrations of all N parameters, TP, and TDP during snowmelt occurred in 2012. The highest average concentrations of N and P parameters, TSS and *E. coli* during rainfall occurred in 2011. For all events combined, average concentrations of N parameters tended to be highest in 2008 and 2009; whereas, concentration of P parameters, TSS, and *E. coli* were highest in 2011.

The comparison of most of the N and P parameter average concentrations between snowmelt and rainfall events at the WHC Sub-watershed outlet was opposite to the IFC Watershed outlet. For example, the average concentrations of TN, ON, NO_3-N and all of the P parameters were highest during rainfall events at the IFC Watershed outlet (Sub-section 3.4.2.1). Also in contrast to WHC were the concentration of Cl and EC, which were higher during snowmelt events at the IFC Watershed outlet.

Overall (all events), the average TN concentration consisted of 77% ON (Table 4.7). This proportion was 61% during snowmelt and 92% during rainfall. These proportions were similar for the IFC Watershed in that the majority of TN was in ON form; however, the percentage values were higher for the WHC Sub-watershed. On average, 88% of TP was in dissolved form (TDP) at the outlet of the WHC Sub-watershed, and similar proportions were observed for snowmelt and rainfall events. This was in contrast to the IFC Watershed, which only had 37% of TP in the form of TDP at the outlet. These data showed that P in water was mainly in dissolved form at the WHC Sub-watershed and mainly is particulate form at the IFC Watershed. This difference was likely due to the differences in hydrology between the two watersheds. The IFC Watershed was more erosive due to greater elevation difference, incised channels, and flashier runoff events; whereas, the WHC Sub-watershed had less elevation difference, shallower channels, and less flashy runoff events. On average, the TSS concentration at the outlet was more than 10-fold greater at IFC compared to WHC. However, this does not explain the similarity of ON being the major proportion of TN at both watersheds. It was assumed that ON was generally in particulate form. If this was true for both watersheds, then we should have expected dissolved inorganic N (NO_3-N, NH_3-N) to have been the majority of the TN in WHC, but this was not the case. Possibly in WHC, a large proportion of ON was in dissolved form, but unfortunately, dissolved organic N was not measured in this study.

The above results generally showed no clear trend among parameters with respect to year. Several parameters during snowmelt (TP, TDP, *E. coli*) and during rainfall (NH_3-N, PP, TSS *E. coli*, pH) were not significantly different among the 5 yr (Tables 4.5 and 4.5a). For all events combined, concentrations of most of the N parameters, all of the P parameters, and TSS were significantly less in 2010 compared to 2011. In contrast, EC was significantly higher in 2010 compared to the other 4 yr.

Regression analysis showed there was essentially no relationship between flow and the concentration of water quality parameters. Even though the regression analysis was significant for several parameters (P <0.1), the r^2 values were equal to or less than 0.28, indicating very weak

Table 4.7. Average N and P parameter c oncentrations at the Whelp Creek Sub-watershed outlet (Station 301) from 2008 to 2012.[z]

Year	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP
		----------	----------	----------	(mg L^{-1})	----------	----------	----------
				Snowmelt				
2008	17	3.59*b*[y]	2.62*a*	0.88*b*	0.07*b*	0.63*a*	0.56*a*	0.08*ab*
2009	4	3.74*ab*	2.39*ab*	1.21*ab*	0.11*ab*	0.56*a*	0.52*a*	0.04*b*
2011	8	4.43*ab*	2.02*b*	2.02*a*	0.37*a*	0.90*a*	0.79*a*	0.11*a*
2012	5	5.56*a*	2.86*a*	2.26*a*	0.43*a*	0.97*a*	0.88*a*	0.10*ab*
All	34	4.10	2.48	1.39	0.20	0.74	0.66	0.08
				Rainfall				
2008	14	2.58*ab*	2.50*a*	0.03*b*	0.03*a*	0.30*b*	0.23*b*	0.07*a*
2010	24	2.19*b*	1.98*b*	0.13a*b*	0.05*a*	0.56*a*	0.50*a*	0.06*a*
2011	16	2.68*a*	2.35*a*	0.27*a*	0.05*a*	0.72*a*	0.62*a*	0.10*a*
2012	8	2.10*b*	1.95*b*	0.14*ab*	0.03*a*	0.31*b*	0.24*b*	0.06*a*
All	62	2.39	2.19	0.15	0.04	0.51	0.44	0.07
				Overall				
2008	31	3.14*a*	2.57*a*	0.50*ab*	0.05*b*	0.48*b*	0.41*b*	0.07*ab*
2009	4	3.74*a*	2.39*ab*	1.21*a*	0.11*ab*	0.56*ab*	0.52*ab*	0.04*ab*
2010	24	2.19*b*	1.98*b*	0.13*b*	0.05*b*	0.56*b*	0.50*b*	0.06*b*
2011	24	3.26*a*	2.24*b*	0.85*a*	0.16*a*	0.78*a*	0.68*a*	0.10*a*
2012	13	3.43*a*	2.30*ab*	0.95*a*	0.18*a*	0.56*ab*	0.49*ab*	0.08*ab*
All	96	3.00	2.30	0.59	0.10	0.59	0.52	0.08

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus.
[y] Averages among years per parameter and event type followed by the same letter are not significantly different (P <0.1).

relationships (Table 4.9). The lack of relationships between flow and concentration at the WHC Sub-watershed was in contrast to the IFC Watershed outlet, where stronger, positive relationships (r^2 = 0.59 to 0.71) occurred between flow and concentrations of TP, PP, and TSS (Sub-section 3.4.2.1). These three parameters were indicative of sediment loss and as flow increased in IFC greater erosion typically occurred. The lack of flow-concentration relationships in the WHC Sub-watershed may have been result of smaller flows, a shallower drainage system, and frequent non-connective flow, compared to IFC Watershed.

Watershed outlet mass loads. Annual nutrient and sediment mass loads increased with annual flow at the outlet of the sub-watershed (Table 4.10). Regression analysis showed a strong relationship ($r^2 > 0.97$; $P < 0.002$) between all parameters and flow. The large annual flow in 2011 was a primary driver in the relationships. However, when the 2011 data were removed, r^2 values remained greater than 0.93 for most of the parameters except for TDP (r^2 = 0.79; P = 0.1) and TP (r^2 = 0.83; P = 0.09). Annual flow was the main factor influencing annual loads at the WHC Sub-watershed outlet. Concentration was likely not a major factor for the relationships because there was little relationship between concentration and flow (Table 4.9).

Table 4.8. Average total suspended solids (TSS), chloride (Cl), *Escherichia coli* (*E. coli*), electrical conductivity (EC), and pH concentrations at the Whelp Creek Sub-watershed outlet (Station 301) from 2008 to 2012.

Year	n	TSS[z] (mg L^{-1})	Cl[y] (mg L^{-1})	*E. coli* (mpn 100 mL^{-1})	EC (µS cm^{-1})	pH
			Snowmelt			
2008	17	7*b*[y]	na[x]	11*a*	725*a*	7.99*b*
2009	4	3*b*	76.7*a*	9*a*	696*a*	8.44*a*
2011	8	17*a*	22.0*c*	54*a*	443*b*	7.76*c*
2012	5	10*ab*	47.9*b*	54*a*	633*a*	7.85*bc*
All	34	9	42.5	29	648	7.97
			Rainfall			
2008	14	12*a*	36.8*ab*	294*a*	862*a*	8.16*a*
2010	24	8*a*	114*a*	7,069*a*	945*a*	8.15*a*
2011	16	17*a*	34.6*b*	15,155*a*	585*b*	8.07*a*
2012	8	15*a*	51.8*b*	61*a*	777*ab*	8.19*a*
All	62	12	76.4	6827	812	8.14
			Overall			
2008	31	9*b*	36.8*abc*	147*a*	787*b*	8.07*bc*
2009	4	3*ab*	76.7*ab*	9*a*	696*bc*	8.44*a*
2010	24	8*b*	114*a*	7,069*a*	945*a*	8.15*b*
2011	24	17*a*	30.4*c*	10,121*a*	542*c*	7.97*c*
2012	13	13*ab*	50.3*bc*	58*a*	722*b*	8.06*bc*
All	96	11	67.6	4,536	755	8.08

[z] TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Averages among years per parameter and event type followed by the same letter are not significantly different (P <0.1).
[y] na = not available. Chloride was added to the analytical suite in late July 2008.

Table 4.9. Whelp Creek Sub-watershed outlet (Station 301) annual flow and water quality parameter concentration relationships.

Parameter[z]	Linear equation	r^2
TP	y = 0.30x + 0.50	0.18*[y]
TDP	y = 0.28x + 0.43	0.18*
PP	y = 0.02x + 0.07	0.03
TN	y = 0.84x + 2.75	0.09*
ON	y = -0.10x + 2.32	0.01
DIN	y = 0.95x + 0.44	0.16*
TSS	y = 2.65x + 10.4	0.01
E. coli	y = 8717x + 1928	0.04*
EC	y = -268x + 833	0.28*
pH	y = -0.13x + 8.11	0.06*
Cl[x]	y = -37.8x + 82.5	0.16*

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

Table 4.10. Annual mass load of nutrients and total suspended solids and annual flow at the outlet (Station 301) from 2008 to 2012.

Variable [z]	2008[y]	2009[x]	2010[w]	2011[v]	2012[u]
TP (kg yr^{-1})	168	17	655	5,522	860
TDP (kg yr^{-1})	144	15	585	4,924	724
PP (kg yr^{-1})	24	2	70	598	136
TN (kg yr^{-1})	1,173	94	1,523	25,432	5,997
ON (kg yr^{-1})	969	58	1,288	12,895	3781
DIN (kg yr^{-1})	204	36	235	12,615	1869
TSS (kg yr^{-1})	3,122	74	7,976	95,831	22,398
Flow (m^3 yr^{-1})	355,999	25,319	644,966	5,896,213	1,686,658

[z] TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TN = total nitrogen, ON = organic nitrogen, DIN = dissolved inorganic nitrogen (NO_3-N plus NH_3-N), TSS = total suspended solids.
[y] Loads calculated from March 21 to July 12.
[x] Loads calculated from April 6 to 28.
[w] Loads calculated from May 21 to October 3.
[v] Loads calculated from April 6 to September 28.
[u] Loads calculated from March 19 to June 30.

4.4.2.2 Watershed-wide Assessment

The concentrations of TN and TP were higher during snowmelt than rainfall runoff at the other watershed-wide sites (Figures 4.13 and 4.14), similar to the outlet as already described previously. For the mainstem stations (Stations 301 and 303), the average concentration of TN and TP decreased from upstream to downstream, and this was more apparent for TP. The water from three tributaries (Stations 304, 305, and 319) entered the mainstem between Stations 303 and 301 (Figure 4.10). The average concentrations of TN at Stations 304 and 305 and TP at Stations 304, 305, and 319 were less than at Station 303. Therefore, water from the tributaries may have had a dilution effect and caused a reduction in concentration from Station 303 to 301. The combined annual flow of the tributary stations represented 23 to 47% of the annual flow at Station 301 (Table 4.6), and therefore, was likely large enough to influence the nutrient concentrations in the mainstem. Even though the concentration of TN at Station 319 was much higher compared to Station 303, there was still a decrease in TN concentration at Station 301. The higher TN concentration at Station 319 (Figure 4.13) likely only had a small influence on the mainstem because the annual flow at Station 319 was small compared to the other two tributary stations (Table 4.6). On average, flow from Station 319 represented less than 10% of the combined flow from the three tributary stations (Table 4.6). The dilution effect caused by the Stations 304 and 305 tributaries was greater on the mainstem than the higher TN concentration from Station 319 resulting in a net reduction in concentration from Station 303 to Station 301.

Similar to the outlet, TN was dominated by ON at most of the other watershed-wide stations and TP was dominated by TDP at all of the stations (Figures 4.13 and 3.14). The exception was at Station 319 where 69% of TN was in the form of dissolved organic nitrogen (DIN). This was an edge-of-field site and possibly more DIN was available from the field. The average concentrations of TN and TP were higher during snowmelt compared to rainfall at all of the stations. For N, the concentration of ON was similar between snowmelt and rainfall. On average among the sites, the ON concentration was 2.5 mg L^{-1} during snowmelt and 2.1 mg L^{-1} during rainfall. In contrast, the concentration of DIN was consistently higher among the stations during snowmelt (6.9 mg L^{-1}) compared to rainfall (0.41 mg L^{-1}). The average concentration of TDP among the sites was nearly two-fold higher during snowmelt compared to rainfall. The higher concentration of dissolved forms of N and P in water during snowmelt may be from nutrient release from crop and other plant residues during the spring thaw.

In contrast to N and P, the average concentration of TSS increased from Station 303 to 301. The average concentrations at Stations 304 and 305 were 3 and 6 mg L^{-1} TSS, respectively, which were similar to Station 303 (6 mg L^{-1}) (Figure 4.15c). However, the concentration was much higher at Station 319, particularly during rainfall (Figure 4.15b). Even though less water was contributed from Station 319 compared to the Stations 304 and 305, as previously described, the TSS concentration at Station 319 may have been high enough to cause an increase from Station 303 to 301. The average TSS at Station 319 was particularly high during rainfall due to high TSS peak concentrations (224 to 1660 mg L^{-1}) in June and July 2011. On June 19, 2011, the landowner used a four-wheel-drive truck to create large ruts to drain excess runoff water from the Reference 2 (REF 2) field, which drained to Station 319. The elevated TSS concentrations in 2011 were due to this disturbance in the field. The difference between snowmelt and rainfall events was not as consistent for TSS compared to N and P. Only Stations 304 and 305 had TSS concentrations higher during snowmelt compared to rainfall (Figure 4.15a,b). The opposite was true for the other three sites.

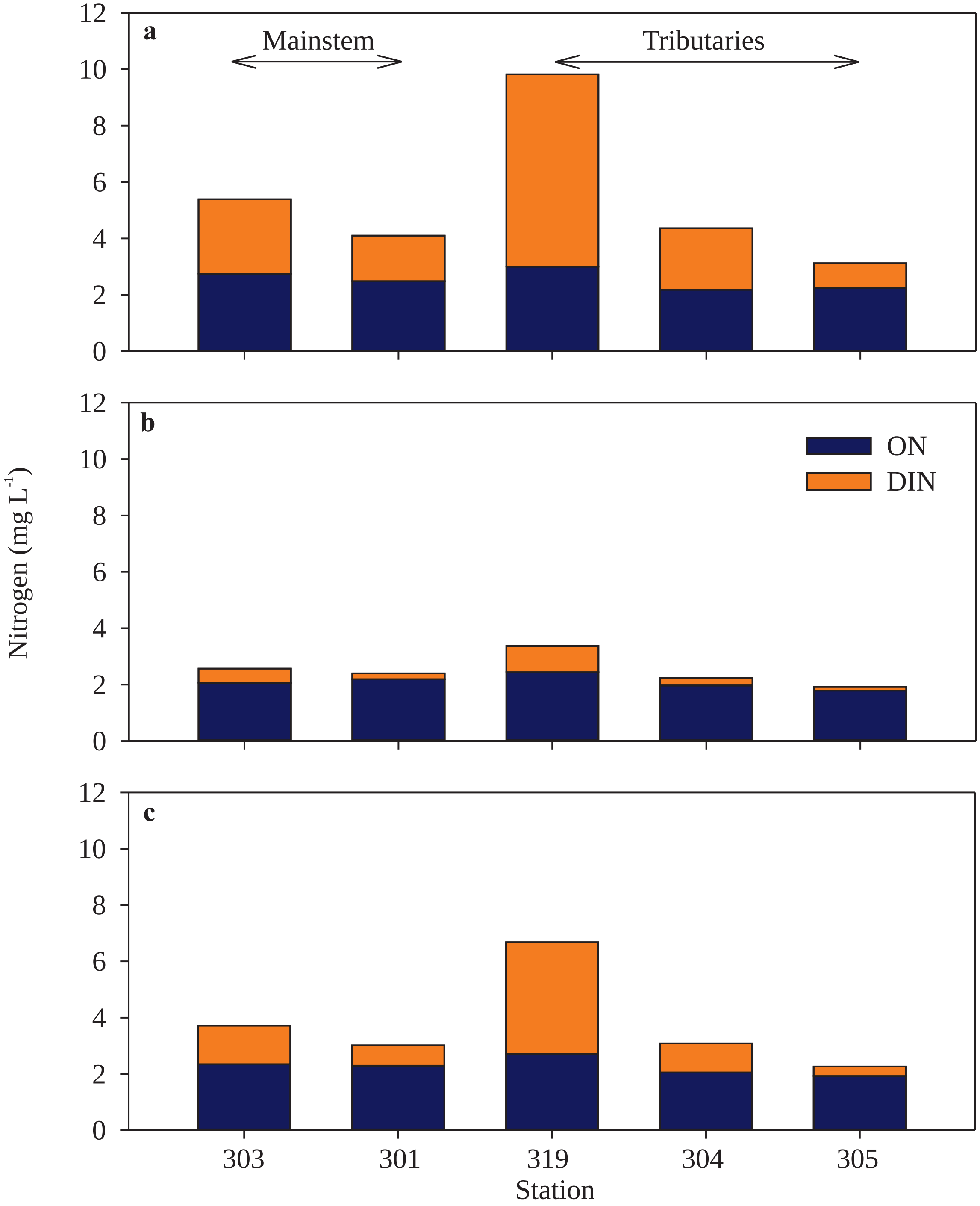

Figure 4.13. Average concentrations of organic nitrogen (ON) and dissolved inorganic nitrogen (DIN; NO_3-N plus NH_3-N)) for (a) snowmelt, (b) rainfall, and (c) both runoff events combined from 2008 to 2012. The mainstem stations are shown from upstream (left) to downstream (right).

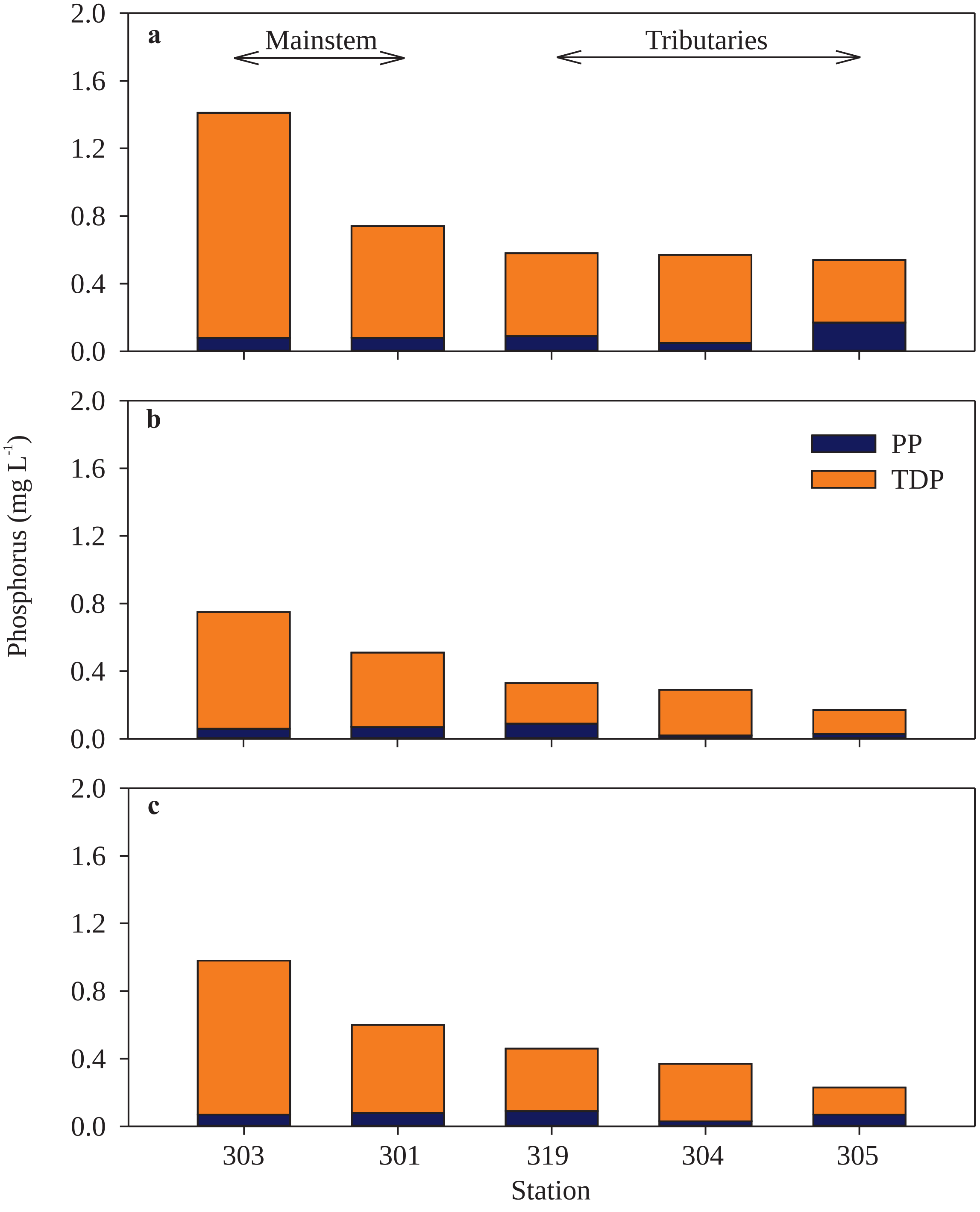

Figure 4.14. Average concentration of particulate phosphorus (PP) and total dissolved phosphorus (TDP) for (a) snowmelt, (b) rainfall, and (c) both runoff events combined from 2008 to 2012. The mainstem stations are shown from upstream (left) to downstream (right).

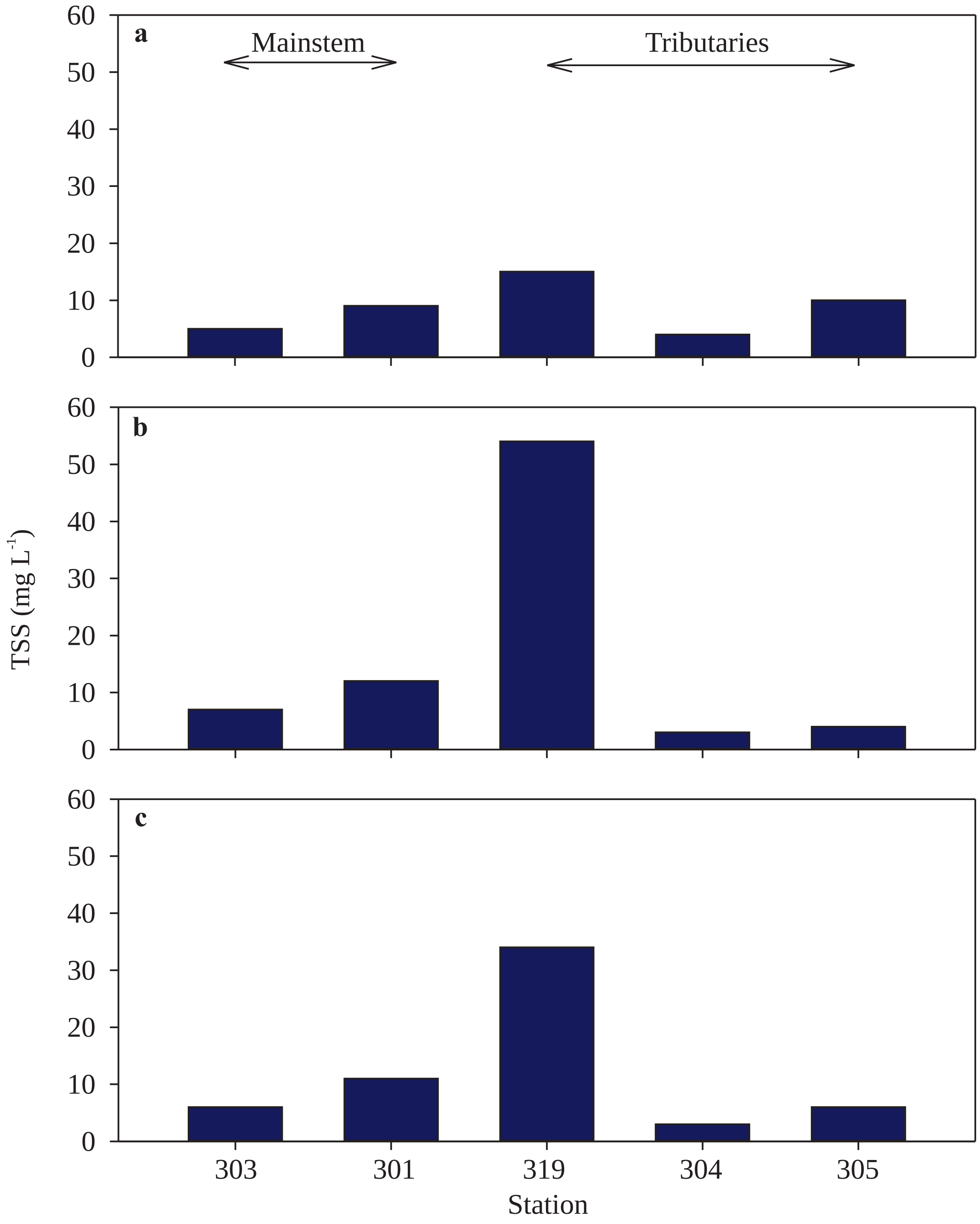

Figure 4.15. Average concentrations of total suspended solid (TSS) from 2008 to 2012 for (a) snowmelt, (b) rainfall, and (c) both runoff events combined from 2008 to 2012. Note the different y-axis scale for each event type. The mainstem stations are shown from upstream (left) to downstream (right).

A few very high concentrations of *E. coli* were measured in the sub-watershed. The highest concentration measured during the study was 613,100 mpn 100 mL^{-1} at Station 303 in July 2010. The second highest *E. coli* concentration was 198,630 mpn 100 mL^{-1} measured at Station 301 in July 2011. The reasons for these peaks in *E. coli* are unknown, but they may have been related to wildlife activity or manure application in the area, as cattle were not present upstream or around the stations during sample collection. Wildlife activity was a probable source of *E. coli* as previous microbial source tracking in this area traced *E. coli* to a muskrat host (unpublished data) and muskrat activity typically increases during spring. These and other high values skewed the dataset, and as a result, medians were used to compare the central tendencies among the stations and event types.

The median concentration of *E. coli* ranged from 6 to 83 during snowmelt and from 259 to 21,738 mpn 100 mL^{-1} during rainfall among the five stations (Figure 4.16a,b). Lower concentration of *E. coli* during the snowmelt period has been reported for other agricultural watersheds in Alberta (Lorenz et al. 2008). This is likely related to colder temperature causing less microbial activity in the early spring compared to rainfall conditions in the late spring and summer. For snowmelt and rainfall events combined, median concentration of *E. coli* was higher at Stations 303 (39 mpn 100 mL^{-1}) and 301 (40 mpn 100 mL^{-1}) compared to the three tributary stations (7 to 24 mpn 100 mL^{-1}) (Figure 4.16c). The slight reduction in concentration from Station 303 to Station 301 may have been caused by a dilution effect from the tributaries.

4.4.2.3 Nutrient Water Quality Sub-Index

In all 5 yr of sampling, the outlet Station 301 had low index scores (<20) (Figure 4.17a), meaning that the water was of poor quality. This was true for Stations 303, 304, and 305, and average scores among the four stations were equally low (Figure 4.17c). The lowest score was in 2011 (Figure 4.17b), which was also the year with the largest annual flow (Table 4.6). Concentrations of NH_3-N, NO_3-N, NO_2-N, and TP were higher in 2011 compared to the other years, while the highest overall TP and TN concentrations were also observed that year. However, the average scores were generally similar among years, with slightly higher scores in 2010 (Figure 4.17a,b). This suggests that even though BMPs were implemented, there was no water quality improvement measureable at the watershed scale. Climate and surface hydrology may have been overriding factors. Also, since only a few small sites relatively to the size of the watershed were implemented with BMPs, the cumulative BMP effects may not have been measurable at the watershed scale. The average NWQS-I score increased slightly from Station 303 to Station 301 (Figure 4.17c). This slight increase may have been caused by the contributions from the tributaries (Stations 304 and 305), which had higher average scores than Station 303.

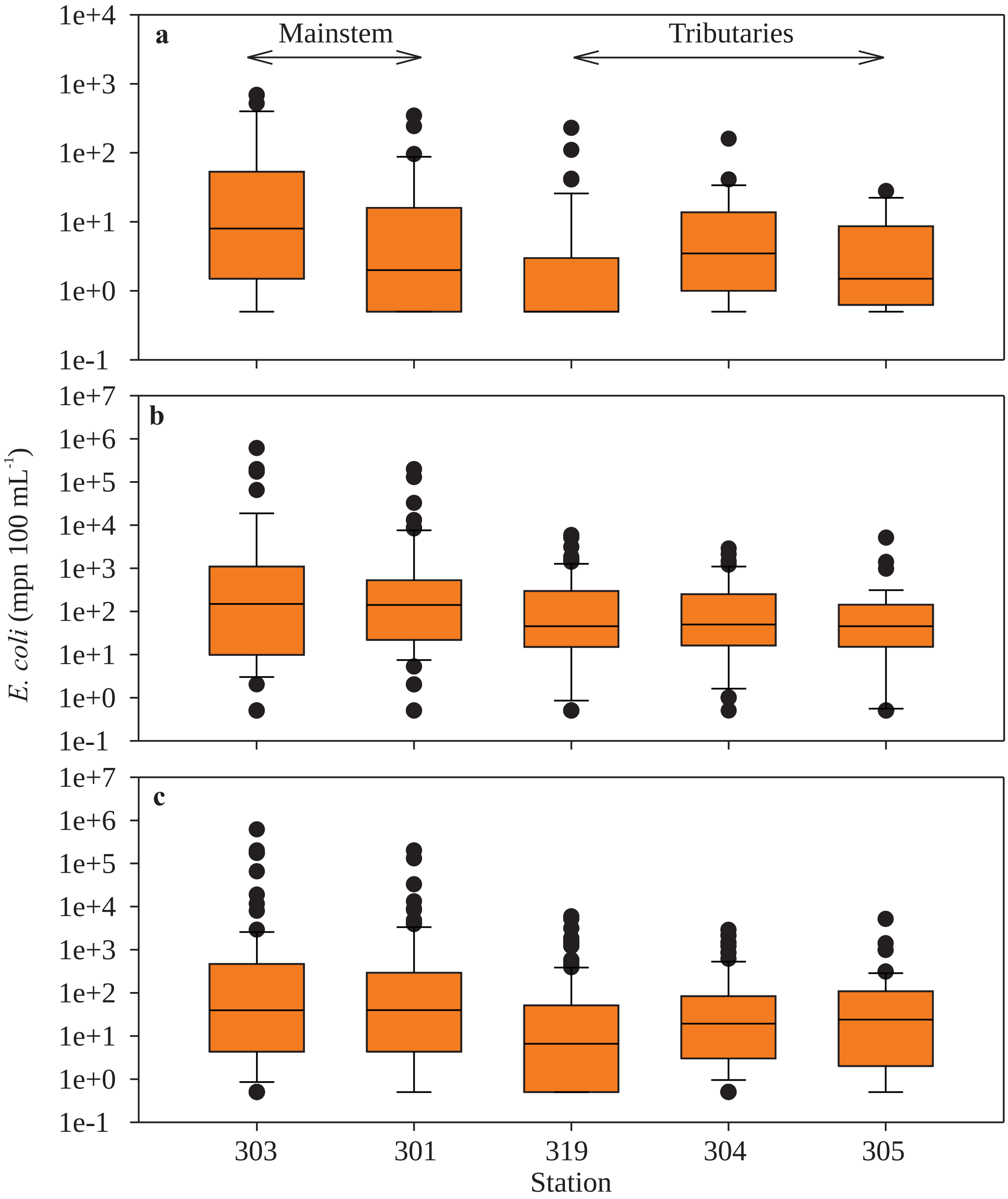

Figure 4.16. Concentrations of *Escherichia coli* (*E. coli*) for (a) snowmelt, (b) rainfall, and (c) both runoff events combined from 2008 to 2012. Note the log scale and different y-axis ranges. The mainstem stations are shown from upstream (left) to downstream (right). The lines within the boxes are the medians, the bottom and top edges of the boxes are the 25th and 75th percentiles, the error bars are the 10th and 90th percentiles, and the dots are outliers.

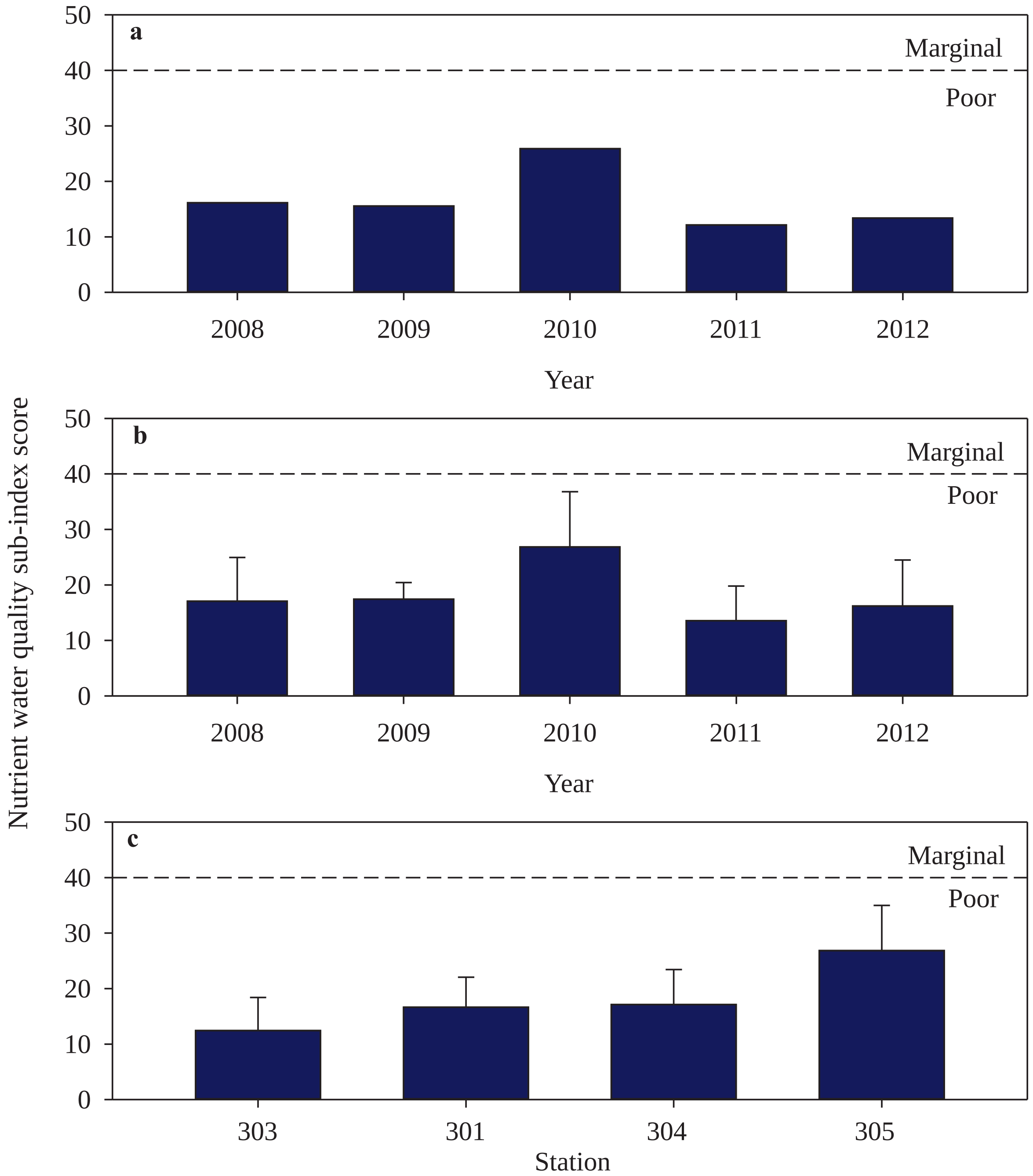

Figure 4.17. Nutrient water quality sub-index scores for (a) the watershed outlet at Station 301 from 2008 to 2012, (b) each year averaged among the watershed-wide stations (n = 4), and (c) each station averaged among the years (n = 5).

4.4.2.4 Comparison to AESA Watersheds

The 5-yr median FWMCs of TN and TP at the outlet of WHC Sub-watershed were 1.9-fold and 3.5-fold greater, respectively, than the median values for the 23 watersheds used in the AESA Water Quality Program from 1999 to 2006 (Lorenz et al. 2008) (Table 4.11). In contrast, the median mass loads of TN and TP were less than the median values for the AESA watersheds.

The median TN and TP concentrations for the 5-yr dataset (n = 96) for the WHC Sub-watershed outlet was higher than median concentrations of the high, moderate, and low agriculture intensity AESA watersheds (Figure 4.18). The WHC Sub-watershed was categorized as a high intensity agriculture watershed, based on the methodology used to categorize relative agriculture intensity for the 23 watersheds used in the AESA Program (Lorenz et al. 2008). Agriculture intensity categories (low, moderate, high) were based on manure production, fertilizer sales, and pesticide sales census data (Johnson and Kirtz 1998; Anderson et al. 1999). Compared to the AESA high agriculture intensity watersheds, WHC Sub-watershed TN and TP concentrations were at the high end of the range for the AESA watersheds. Of the eight high agriculture intensity AESA watersheds, only one watershed for TN and two watershed for TP had higher median concentrations (Lorenz et al. 2008; data not shown) than the WHC Sub-watershed.

Table 4.11. Median, minimum (Min.), and maximum (Max.) values for annual flow-weight mean concentrations and annual mass loads of total phosphorus (TP) and total nitrogen (TN) for outlets of the Whelp Creek Sub-watershed (WHC) and the Alberta Environmentally Sustainable Agriculture (AESA) Program watersheds.

	Annual flow-weight mean concentration						Annual mass load					
	WHC[z]			AESA[y]			WHC[z]			AESA[y]		
	Median	Min.	Max.	Median	Min.	Max.	Median	Min.	Max.	Median	Min.	Max.
Parameter	(mg L^{-1})						(Mg yr^{-1})					
TN	3.6	2.4	4.3	1.9	0.1	8.6	1.5	0.09	25.4	10.0	0.08	198.6
TP	0.7	0.5	1.0	0.2	0.0	1.3	0.7	0.02	5.5	1.2	0.002	70.6

[z] Dataset from 2008 to 2012 (n = 5).
[y] Dataset 1999 to 2006 (Lorenz et al. 2008) for 22 watersheds for 8 yr, less 4 yr for one watershed and less 1 yr in another watershed (n = 171).

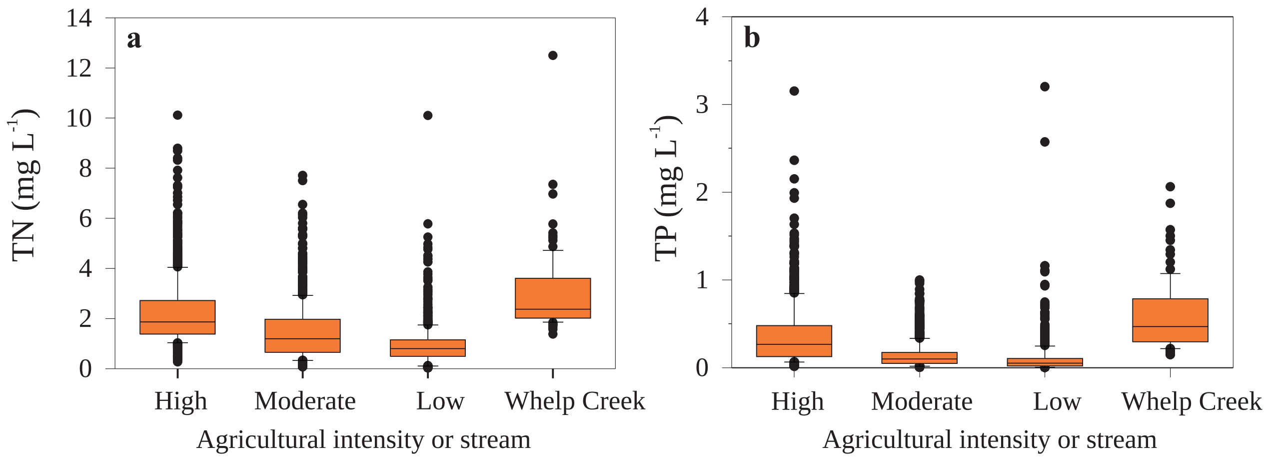

Figure 4.18. Instream concentrations of (a) total nitrogen (TN) and (b) total phosphorus (TP) in Whelp Creek (WHC) Sub-watershed (n = 96) compared to values observed for high (eight watersheds; n = 889), moderate (six watersheds; n = 831), and low (five watersheds; n = 730) agricultural intensity AESA watersheds (Lorenz et al. 2008). The four irrigated AESA watersheds were not included in these graphs. For a smaller y-axis and to ease comparison among intensities, a TN concentration of 28 mg L^{-1} was not shown for the low intensity AESA watersheds in Figure 4.18a.

4.4.2.5 Synoptic Survey

2009 synoptic survey (low flow). Overall, flow was low in the sub-watershed during the 2009 synoptic survey, and ranged from 0.00005 to 0.011 $m^3 s^{-1}$ depending on the location in the watershed (Figure 4.19a). Flow generally increased along the mainstem towards the outlet of the sub-watershed. Contributions from tributary Sites 5 and 8 were very small, and this resulted in no change in flow from Site 6 (upstream) to Site 7 (downstream). The relatively large increase in flow from Site 13 to Site 15 was the result of contribution at tributary Site 13. The flow then decreased from Site 15 to the outlet at Site 16. This decrease was not surprising because water was observed pooled near Site 16 during the low-flow conditions. Flow occurred at only four sites on the southern tributary and the flow was very low at Site 17.

In 2009, the concentration of TN ranged from 1.7 to 10.3 mg L^{-1} (Figure 4.20a), with an average of 3.8 mg L^{-1}. The concentration of TN varied along the mainstem, with no consistent trend. In fact, the concentration between the furthest upstream site (Site 3) and the outlet (Site 16) had similar TN concentrations. The concentration of TN at most tributary sites was similar to the mainstem, except for tributary Site 5, which had the highest concentration measured during the 2009 synoptic survey. The high concentration at Site 5 may have affected the mainstem as TN concentration increased by 0.63 mg L^{-1} from upstream (Site 6) to downstream (Site 7). However, the flow at Site 5 was much smaller than at Site 6 (Figure 4.19a). The proportion of TN in the form of DIN ranged from 4 to 57%, with an average of 30%.

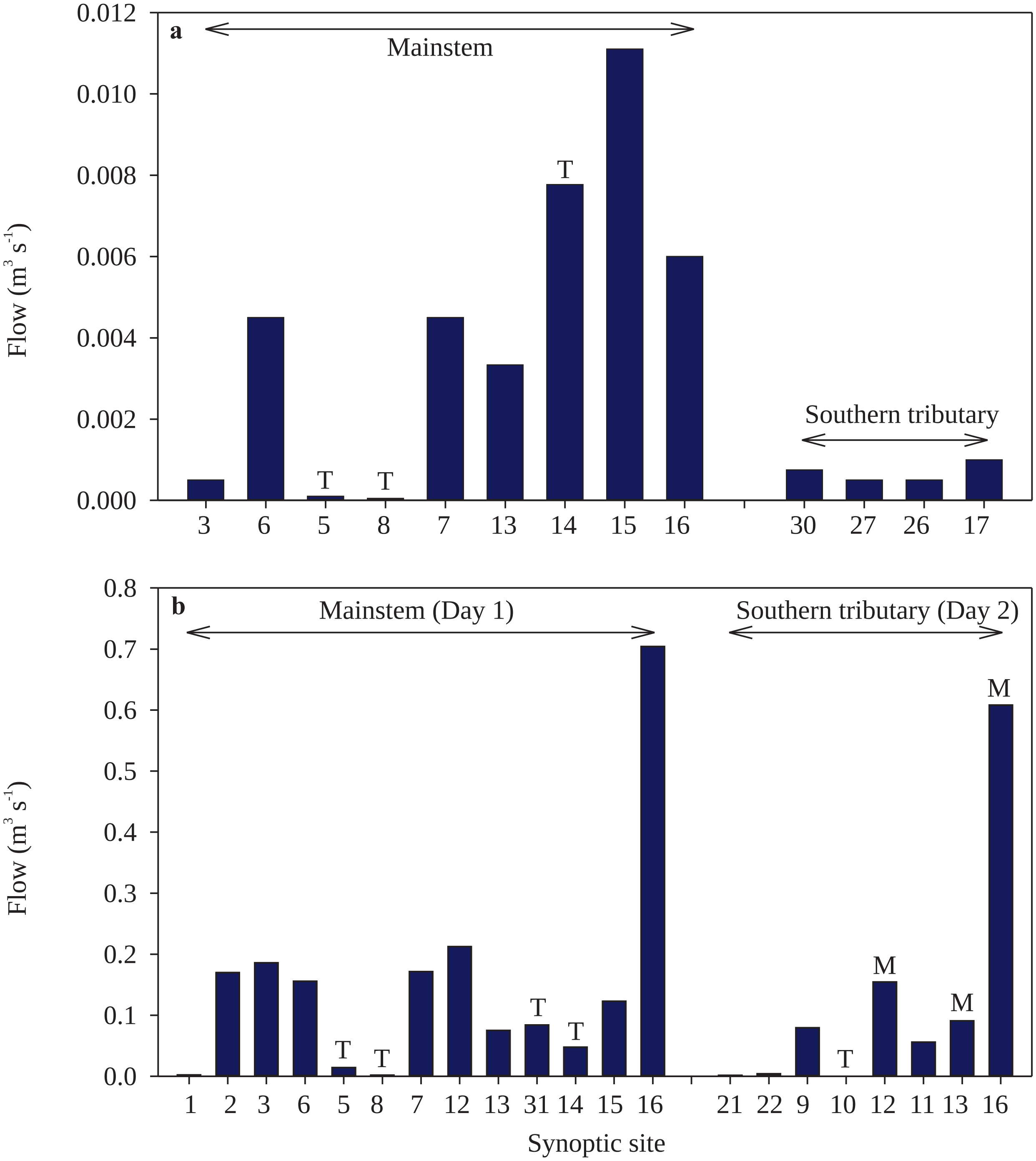

Figure 4.19. Flow measured during the (a) 2009 and (b) 2011 synoptic surveys in Whelp Creek Sub-watershed. T = small tributaries on the mainstem; M = mainstem sites sampled in association with the tributary sites in 2011.

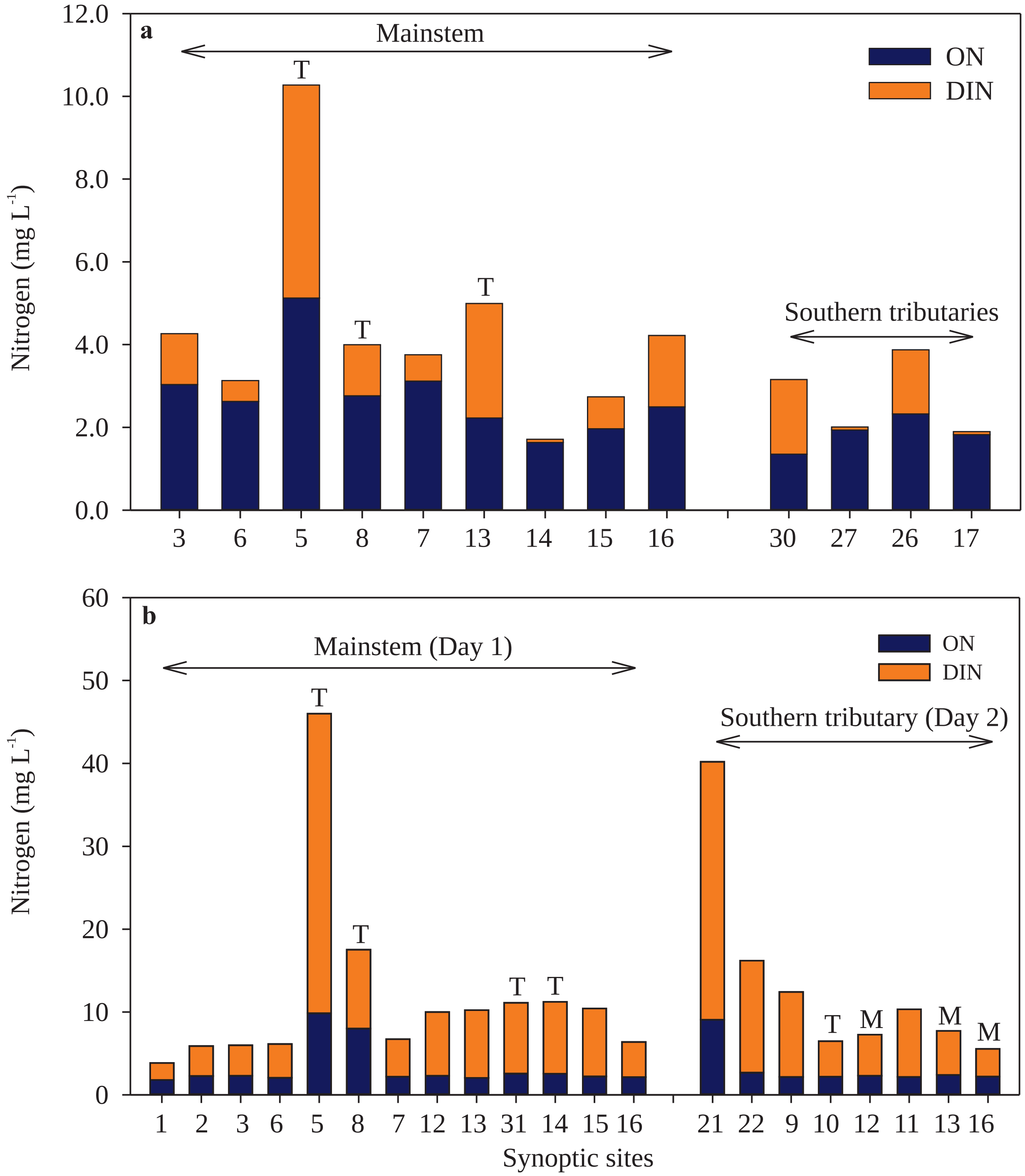

Figure 4.20. Concentrations of dissolved inorganic nitrogen (DIN; NO_3-N plus NH_3-N) and organic nitrogen (ON) for the (a) 2009 and (b) 2011 synoptic survey sites in the Whelp Creek Sub-watershed. Total nitrogen equals DIN plus ON. T = small tributaries on the mainstem; M = mainstem sites sampled in association with the tributary sites in 2011.

The concentration of TP in the mainstem decreased about 28% from the headwaters (Site 3) to the outlet (Site 16) (Figure 4.21a). The average concentration among the mainstem sites was 0.62 mg L^{-1}. Tributary Sites 5 and 8 had higher TP concentrations compared to the mainstem sites; however, neither appeared to have influenced the downstream Site 7. The lack of an increase was likely related to the low flow in these tributaries, which had 45 to 90 times lower flow than the mainstem sites (Figure 4.19a). The concentration of TP also decreased as water flowed downstream in the south tributary (Figure 4.21a). On average, TP concentration was less in the south tributary compared to the mainstem. The proportion of TP in the form of TDP ranged from 83 to 100% among the sites (Figure 4.21a), and the majority of TDP (53 to 90%) was in the form of orthophosphate, which is the most bioavailable form of P and has implication for eutrophication downstream. A high proportion of TP as TDP suggest there was relatively little sediment loss, and therefore, little PP loss in the runoff water.

The concentration of TSS was less than the method detection limit (MDL) of 3.0 mg L^{-1} at a majority of sites during the synoptic survey (Figure 4.22a). The highest concentration was at tributary Site 8; however, the contribution from this tributary had no measureable effect on the mainstem. On the southern tributary, TSS concentration was above the MDL at Sites 26 and 27. Bare soil near Site 26 may have contributed to the higher TSS concentration. The overall low TSS concentration during the synoptic survey was likely the result of minimal soil erosion because of very low flow conditions.

The concentrations of *E. coli* at the sites were low (less than 40 mpn 100 mL^{-1}) throughout sub-watershed (Figure 4.23a). Overall, the average concentration was 8 mpn 100 mL^{-1}. The low average was not surprising because the synoptic survey was completed during snowmelt conditions, which typical has low microbial activity. There was no obvious trend from the headwaters to the outlet along the mainstem or along the southern tributary. The tributary sites had lower *E. coli* concentrations (average = 2 mpn 100 mL^{-1}) compared to the mainstem sites (average = 15 mpn 100 mL^{-1}). Sites 7 and 13 had the highest *E. coli* concentrations at 24 and 37 mpn 100 mL^{-1}, respectively. The higher concentration at Site 13 may have been the result of wildlife, since a forested area and grassed waterway were upstream from this site.

2011 synoptic survey (high flow). Flow during the 2011 synoptic survey was relatively low, but was much higher than during the 2009 synoptic survey, ranging from 0.001 to 0.704 $m^3 s^{-1}$. The highest flow values occurred at the outlet on Days 1 and 2, with flows of 0.704 and 0.608 $m^3 s^{-1}$, respectively (Synoptic Site 16, Figure 4.19b). These flow values were 55- to 64-fold greater than the highest flow measured during the 2009 synoptic survey at Site 15 (Figure 4.19a). Flow was relatively consistent along the mainstem from Site 2 to Site 12. The contributions from tributary Sites 5 and 8 were small in this reach of the mainstem. The decrease in flow after Site 12 to Site 15 may have been caused by partially pooled water and/or groundwater recharge. The decrease in flow from Site 12 to Site 13 was consistent for Days 1 and 2. From Site 15 to Site 16, flow then increased by nearly 6-fold. This increase in flow was likely caused by sources of water not monitored, as the flow contribution from the tributary Site 11 measured on Day 2 was small (Figure 4.19b) and there was no flow from the Site 19 tributary system.

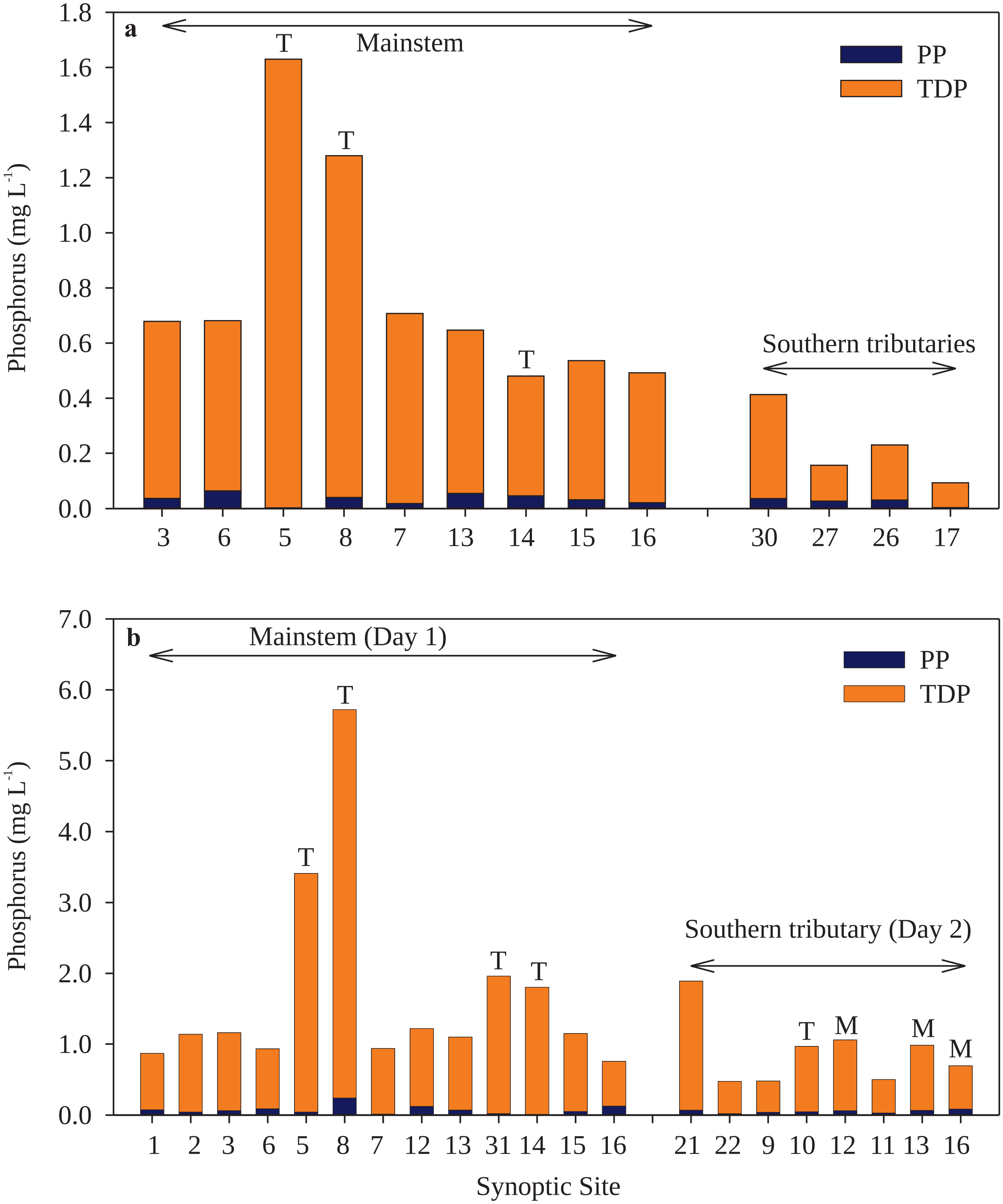

Figure 4.21. Concentrations of total dissolved phosphorus (TDP) and particulate phosphorus (PP) for the (a) 2009 and (b) 2011 synoptic survey sites in the Whelp Creek Sub-watershed. Total phosphorus equals TDP plus PP. T = small tributaries on the mainstem; M = mainstem sites sampled in association with the tributary sites in 2011.

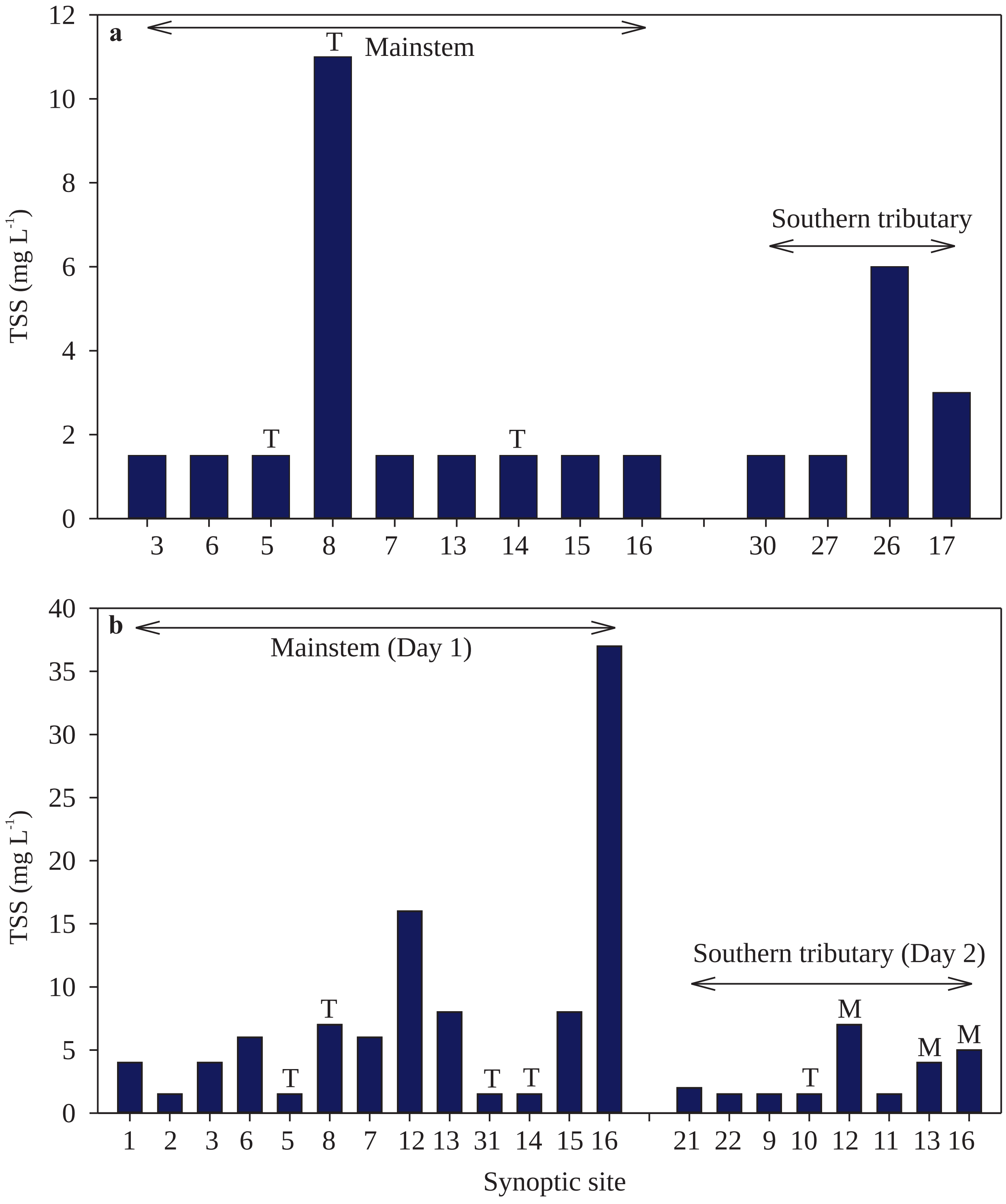

Figure 4.22. Concentration of total suspended solids (TSS) for the (a) 2009 and (b) 2011 synoptic survey sites in the Whelp Creek Sub-watershed. T = small tributaries on the mainstem; M = mainstem sites sampled in association with the tributary sites in 2011.

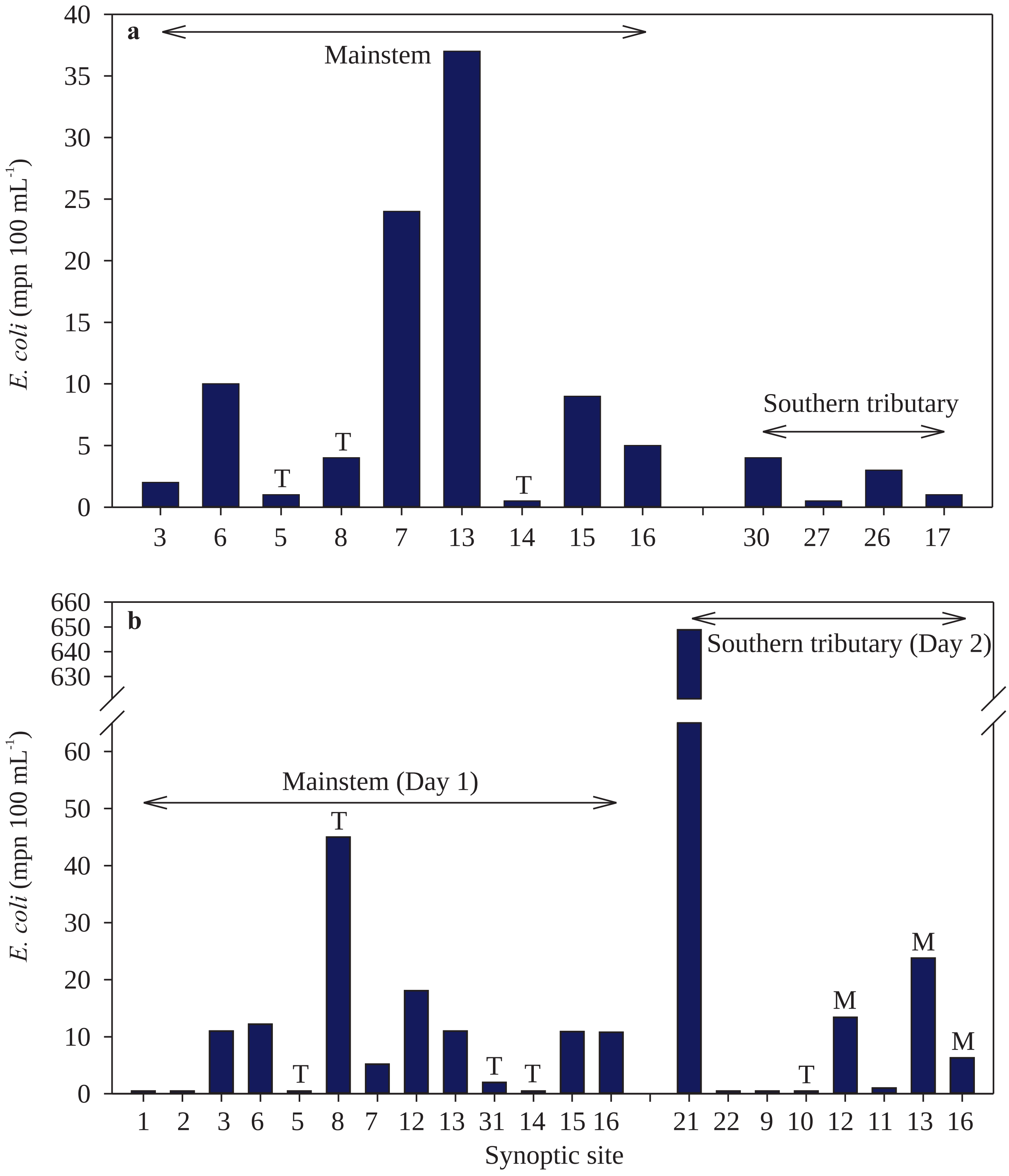

Figure 4.23. Concentrations of *Escherichia coli* (*E. coli*) for the (a) 2009 and (b) 2011 synoptic survey sites in the Whelp Creek Sub-watershed. T = small tributaries on the mainstem; M = mainstem sites sampled in association with the tributary sites in 2011.

Total N concentration ranged from 3.8 to 46 mg L^{-1}, with an average of 12.3 mg L^{-1} (Figure 4.20b). On average, the concentration was higher during the 2011 synoptic survey compared to the 2009 synoptic survey. For example, at the outlet, TN concentration was 51% greater in 2011 compared to 2009. The concentration of TN increased from upstream to downstream along most of the mainstem. However, after Site 15, the concentration decreased towards the outlet. A similar decreased from Site 13 to Site 16 was also observed on Day 2. The much higher concentration values at tributary Sites 5 and 8 had little effect on the mainstem because the flows at these two tributaries were small compared to the mainstem (Figure 4.19b). Even though the flow was higher for the tributary Site 14, the concentration of TN along this tributary was similar to the mainstem, and as a result did not affect the TN concentration in the mainstem. The highest concentration of TN for the southern tributary was at the furthest upstream site sampled (Site 21) (Figure 4.20b). Concentration then steadily decreased downstream from Site 21 to Site 11, suggesting possible attenuation or dilution as the water moved downstream. The concentration at Site 11 was higher compared to the upstream Site 12 on the mainstem. However, because of the lower flow at Site 11 compared to the mainstem (Figure 4.19b), the higher concentration of TN from the Site 11 tributary had minimal effect on the mainstem, as the TN concentration was similar between Sites 12 and 13. In contrast to the 2009 synoptic survey, the majority of TN was in DIN form rather than ON form in 2011. The proportion of TN as DIN ranged from 53 to 83%, with an average of 71%.

There was no consistent increase or decrease in TP concentration from upstream to downstream among the mainstem sites (Figure 4.21b). However, the outlet site had the lowest concentration among the eight mainstem sites on Day 1. This was also true for the three mainstem sites, including the outlet, sampled on Day 2. The average TP concentration among the mainstem sites was 1.0 mg L^{-1} on Day 1. As with TN, tributary Sites 5, 8, and 14 had higher concentrations than the mainstem. Also similar to TN, the higher concentrations of TP in these tributaries had no discernible effect on the mainstem. Again, this can be attributed to the much lower flow in the tributaries compared to the mainstem (Figure 4.19b). This was also observed in 2009 for tributary Sites 5 and 8 (Figure 4.21a). Similar to TN, Site 21 also had the highest TP concentration on southern tributary and then the concentration decreased downstream (Figure 4.21b). The concentration of TP at Site 11 was less than at the Site 12 on the mainstem on Day 2 and may have caused the slight decrease in concentration from Site 12 to Site 13. As observed for the 2009 synoptic survey, most of the TP (83 to 100%) was in the form of TDP during the 2011 synoptic survey. Again, this suggests minimal loss of PP in the form of sediment.

Similar to the other water quality parameters, TSS concentration was generally higher in 2011 than in 2009. The majority of sites had TSS concentration greater than the MDL of 3.0 mg L^{-1}, though at several sites, TSS concentration was less than the MDL and most of these sites were on tributaries (Figure 4.22b). The higher concentrations in 2011, particularly on the mainstem, were likely the result more sediment erosion caused by greater flows (Figure 4.19). There was a general increase in TSS concentrations towards the outlet on the mainstem, and the highest TSS concentration was at the outlet on Day 1. The nearly 5-fold increase in TSS concentration from Site 15 to Site 16 corresponded with nearly a 6-fold increase in flow (Figure 4.19b). The second highest TSS concentration was measured at Site 12 on Day 1, and the concentration decreased by half downstream at Site 13. This was also observed on Day 2. One of the southern tributaries entered the mainstem between Sites 12 and 13. On Day 2, the concentration at tributary Site 11 was much less then at Site 12, and contributions from the tributary to the mainstem may have had a dilution effect on TSS concentration between Sites 12 and 13. Plus, the flow decreased from Site 12 to Site 13 on both days (Figure 4.19b), and this may have also contributed to the reduction in TSS concentration. It is interesting that from Day 1 to Day 2, TSS concentration decreased by more than seven-fold at Site 1 and by about two-fold at Sites 12 and 13 (Figure 4.22b), even though flow decreased by only 27 and 17% at Sites 12 and 16, respectively, and actually increased by 21% at Site 13 (Figure 4.19b).

In general, the concentrations of *E. coli* was similar to the 2009 synoptic survey, expect for Site 21, which had a concentration of 649 mpn 100 mL^{-1} (Figure 4.23b). Without Site 21, the overall average among the other sites was 9 mpn 100 mL^{-1}. On the mainstem, *E. coli* concentration after Site 2 was generally consistent as water flowed downstream to the outlet. Tributary Site 5, which was downstream from a dairy farm, had a peak concentration of 45 mpn 100 mL^{-1}, but did not seem to influence the concentration in the mainstem, since *E. coli* concentration actually decreased from Site 6 to Site 7. The cause of the very high concentration and source of *E. coli* at Site 21 is unknown. However, this site was in a pasture area where there was evidence of cattle access (i.e., manure) to the stream. Downstream from Site 21, *E. coli* concentration decreased to 0.5 mpn 100 mL^{-1} at Site 22 and then remained low as water flowed along the southern tributary to Site 11.

Comparing the 2009 and 2011 synoptic surveys. Fewer sampling sites had flow during the 2009 synoptic survey compared to the 2011 synoptic survey, and those sites with water in 2009 had much less flow compared to the 2011. Sites with flow in 2009 had an average flow of 0.003 $m^3\ s^{-1}$, compared to 0.14 $m^3\ s^{-1}$ in 2011. The flow at the outlet (Site 16) was 0.006 $m^3\ s^{-1}$ in 2009 and 0.7 $m^3\ s^{-1}$ in 2011 (Figure 4.19). In comparison, the average flow at the outlet for the month of April measured from 2008 to 2012 ranged from no flow to 3.37 $m^3\ s^{-1}$. The maximum flow recorded at the outlet during the 5-yr study was 3.65 $m^3\ s^{-1}$ in late July 2011. The flow at the outlet during the higher flow synoptic survey in 2011 was greater than the April averages for 2008 (0.028 $m^3\ s^{-1}$), 2009 (0.008 $m^3\ s^{-1}$), and 2010 (no flow), and was less than the April averages in 2011 (1.15 $m^3\ s^{-1}$) and 2012 (0.24 $m^3\ s^{-1}$). Therefore, the flow conditions during the synoptic survey in 2011 were typical for April; whereas, the 2009 synoptic survey represented very low flow conditions.

The concentrations of TN, TP, and TSS were generally higher in 2011 compared to 2009 (Figures 4.20 to 4.22). For the sites that had flow, the average concentrations of TN were three-fold higher, TP was two-fold higher, and TSS was two-fold higher in 2011 compared to 2009. In contrast, the concentration of *E. coli* was similar between the two synoptic surveys. The similarity between the two years was likely caused by the cold conditions during April snowmelt, which likely caused minimal microbial activity.

It was interesting how the relative proportions of DIN and ON and the relative proportions of TDP and PP differed between the two synoptic surveys. During both surveys, most of the TP (about 90%) was in the TDP form. However, in 2009, only 30% TN was in DIN form; whereas, in

2011, 71% of TN was in DIN form. As indicated above, the high proportion of TP in dissolved form suggests relatively little sediment loss, and therefore, little PP loss. In this study, we assumed that ON was mainly associated with particulate material. Possibly, the high proportion of ON in 2009 may have been caused by dissolved organic N, which was not measured in this study.

In 2009, there was no increasing or decreasing trend in the concentrations of TN, TSS, or *E. coli* from upstream to downstream on the mainstem; whereas, TP concentration generally decreased as water moved downstream. In 2011, the concentrations of TN and *E. coli* showed no changed along the mainstem; whereas, the concentration of TN and TSS increased from upstream to downstream. The inconsistent change or lack of change in parameter concentrations from upstream to downstream on the mainstem may have been caused by the relative low flows, non-connective flow, and relatively short distance (8.6 km) used for the surveys along the mainstem.

For the most part, the tributaries had minimal influence on the mainstem and this primarily was due to lower flows in the tributaries compared to the mainstem. However, there were a few examples were the contribution from tributaries may have affected the mainstem, such as a dilution effect of TP between Sites 12 and 13 caused by lower concentration from tributary Site 11 in 2011.

4.4.2.6 Streambed Sediment

The concentration of STP in sediment samples collected in April 2009 ranged from 4 to 72 mg kg^{-1}, with an average of 27 mg kg^{-1} (Table 4.12). Nearly all of samples had less than 60 mg kg^{-1} STP, which is considered the agronomic threshold for cultivated crops (Howard 2006). The PSI values were relatively high, ranging from 115 to 559 mg kg^{-1}. The DPS values were low for nearly all of the sediment samples, with nearly all samples less than 25%. One sediment sample had a DPS of 31%. These results suggest that sediment in the drainage channels was low in P and was not a major source of P in terms of desorption from sediment material to the water column. Soils with DPS values from 25 to 40% are considered to have a greater risk of P loss to runoff water (Pautler and Sims 2000). Most of the DPS values for the WHC Sub-watershed sediments samples were also less than values found in manured and non-manured crop fields (4 to 94%) in Alberta reported by Casson et al. (2006). The low DPS values indicate the channel sediment in WHC Sub-watershed have a large capacity to sorb P.

Land cover did not have a major influence on STP concentration or DPS in the sediment samples (Table 4.12). Averages were similar among the five land cover groups, with slightly higher average STP concentration and DPS values for forested land cover sites. These slightly higher values in the forested channels may have been caused by vegetative cover that trapped sediment and accumulated plant residue material and caused a modest accumulation of P. The regression analysis between sediment DPS and TDP concentration in water showed no relationship between these two parameters ($r^2 = 0.007$, $F = 0.079$, $P = 0.78$).

Table 4.12 . Channel width, soil-test phosphorus (STP), phosphorus saturation index (PSI), and degree of phosphorus saturation (DPS for channel sediment samples collected in the Whelp Creek Sub -watershed in April 2009.

Land cover	Site or station	Channel width (m)	STP (mg kg^{-1})	PSI (mg kg^{-1})	DPS (%)
Cropped	310	2.5	6.14	256	2.4
	24	4.0	22.4	355	5.9
Average[z]			*14.3 ± 11.5*	*306 ± 70*	*4.2 ± 2.5*
Grassed	5	0.7	31.9	210	13.2
	8	0.8	60.8	209	22.6
	23	7.5	33.7	452	6.9
	25	7.0	6.72	277	2.4
	313	2.6	4.44	234	1.9
	26	2.1	11.0	316	3.4
Average			*24.8 ± 21.7*	*283 ± 03*	*8.4 ± 8.1*
Forested	6	0.9	19.7	170	10.4
	11	1.0	30.4	203	13.0
	12	0.8	51.7	170	23.3
	14	0.8	33.3	115	22.4
	21	3.4	19.9	389	4.9
	22	5.5	72.8	163	30.9
Average			*38.0 ± 20.7*	*202 ± 96*	*17.5 ± 9.7*
Grazed	7	3.8	15.6	299	4.9
	15	3.2	28.4	289	6.0
Average			*22.0 ± 9.1*	*294 ± 7.0*	*5.5 ± 0.8*
Wetland	3	1.5	34.8	289	10.8
	13	5.3	27.1	428	6.0
	16	15.5	15.6	559	2.7
	19	6.0	10.8	223	4.6
Average			*22.1 ± 10.9*	*375 ± 150*	*6.0 ± 3.5*
Overall average			*26.9 ± 18.2*	*280 ± 111*	*9.9 ± 8.5*

[z] ± standard deviation.

4.4.3 Conclusions

Watershed Outlet:

- During the 5-yr study, annual flow at the watershed outlet ranged from 0.03 million m^3 yr^{-1} in 2009 to 5.9 million m^3 yr^{-1} in 2011.
- The contribution of snowmelt and rainfall runoff to flow in WHC varied widely, with all flow in 2009 caused by rainfall and all flow in 2010 caused by snowmelt. On average, 45% of annual flow at the watershed outlet occurred during snowmelt. The remaining 55% was caused by rainfall and base flow, of which rainfall was more dominant.
- Flow typically began in April at the outlet and generally continued into the spring and/or summer. The shortest flow period occurred in April 2009. The longest period of flow was from April to November 2011.

- Above average precipitation in 2010 and 2011 may have caused higher antecedent soil moisture in 2011, and this may have contributed to more runoff and high flows in 2011. It was hypothesized that in the WHC Sub-watershed previous precipitation amounts likely affect soil moisture and groundwater recharge. This, along with current precipitation, can influence runoff and annual flow in a given year.
- The average concentration of all N parameters, TP, and TDP were highest during snowmelt events; whereas, TSS and *E. coli* concentrations and EC and pH were highest in rainfall runoff.
- The majority of TP was in TDP form (88%) and the majority of TN was in ON form (77%).
- Average concentrations of TN, ON, NO_3-N were highest in 2008 or 2009, and average concentrations of TP, TDP, and PP were highest in 2011.
- There was no clear trend among parameters with respect to year. The concentration of several parameters during snowmelt (TP, TDP, *E. coli*) and during rainfall (NH_3-N, PP, TSS *E. coli*, pH) were not significantly different among the 5 yr. For all events combined, concentrations of most N parameters, all of the P parameters, and TSS were significantly less in 2010 compared to 2011. In contrast, EC was significantly higher in 2010 compared to the other four years.
- There was essentially no relationship between flow and the concentration of water quality parameters. Even though the regression analysis was significant for several parameters (P <0.1), the r^2 values were equal to or less than 0.28, indicating very weak relationships.
- Flow was a primary driver for mass load differences of nutrients and TSS among the years. The smallest mass loads were in 2008 and 2009 (low-flow years) and the largest loads were in 2011 and 2012 (high-flow years).

Watershed-wide Assessment:

- Similar to the outlet, concentrations of TP and TN were higher during snowmelt than rainfall runoff at the other watershed-wide sites. The higher concentrations during snowmelt were mainly caused by higher concentration of dissolved forms of TN (NO_3-N and NH_3-N) and TP (TDP). It was speculated that the higher concentration of dissolved forms of N and P in water during snowmelt may have been from nutrient release from crop and other plant residues during the spring thaw.
- The average concentrations of TN and TP decreased from the upstream mainstem Station 303 to the outlet, and this reduction was attributed to a dilution effect by the southern tributaries, which had lower TN and TP concentrations.
- The higher TN concentration at Station 319 had a small influence on TN and TP concentration in the mainstem because the annual flow at Station 319 was small compared to the combined annual flows of the tributaries.

- The concentration of TSS increased from upstream to downstream on the mainstem. This increase may have been caused by the contribution of Station 319, which had much high TSS concentrations than the mainstem. The average concentration of TSS was less in the main tributaries compared to the mainstem. There was no consistent trend in TSS concentration between snowmelt or rainfall period among the stations.
- The concentration of *E. coli* was higher during rainfall runoff events than during snowmelt events, reflecting less microbial activity during the colder conditions of snowmelt. The median concentration of *E. coli* was higher in the mainstem compared to the tributaries.

Nutrient Water Quality Sub-index:

- The NWQS-I scores for all sites and in all years were rated as poor, i.e., index scores were less than 41.
- The lowest average NWQS-I score was in 2011, which also had the highest annual flow compared to the other years.
- The average NWQS-I scores were similar among years, suggesting the implemented BMPs had no measurable effect on the improvement of water quality at the watershed scale. The BMPs were implemented on only a few small areas compared to the size of the watershed, and it was not expected to measure a BMP effect at the watershed scale.

Comparison to the AESA Watersheds:

- The WHC Sub-watershed was rated as a high-intensity agriculture watershed.
- The median of the annual FWMCs of TN and TP for the WHC Sub-watershed were higher than for the 23 AESA watersheds.
- In contrast, median loads of TN and TP were less for the WHC Sub-watersheds compared to the AESA watersheds.
- The median concentrations of TN and TP for the WHC Sub-watershed were higher than median concentration of the combined eight high-intensity AESA watersheds.

Synoptic Surveys:

- The 2009 synoptic survey represented very low flow conditions; whereas, flow was higher during the 2011 synoptic survey and represented typical snowmelt-generated flow for the month of April in WHC.
- At the outlet, flow during the high-flow synoptic survey was more than a 100-fold greater than during the low-flow synoptic survey.

- The concentrations of TN, TP, and TSS were generally higher during the high-flow synoptic survey compared to the low-flow synoptic survey. For the sites that had flow, the average concentrations of TN were three-fold higher, TP was two-fold higher, and TSS was two-fold higher during high-flow compared to low-flow conditions. In contrast, the concentration of *E. coli* was similar between the two synoptic surveys.
- There was no increasing or decreasing trend in the concentrations of TN, TSS, or *E. coli* in the mainstem; whereas, TP concentration generally decreased as water moved downstream during the low-flow synoptic survey. The concentrations of TN and *E. coli* showed no change along the mainstem; whereas, the concentration of TN and TSS increased from upstream to downstream during the high-flow synoptic survey.
- The inconsistent change or lack of change in parameter concentrations in the mainstem may have been caused by the relative low flows, non-connective flow, and relatively short distance (8.6 km) used for the surveys along the mainstem.
- Generally, the tributaries had minimal influence on the mainstem and this was primarily due to lower flows in the tributaries compared to the mainstem.

Streambed Sediment:

- The average concentration of STP in sediment samples was less than the agronomic threshold and the DPS values were relatively low. These results suggest that sediment in the drainage channels in WHC was low in P with a large capacity to sorb P.
- Land cover did not have a major influence on STP concentration or DPS in the sediment samples.
- The regression analysis between sediment DPS and TDP concentration in water showed no relationship between these two parameters.

4.5 Watershed Groundwater Hydrology and Quality

Groundwater and surface water interactions are not always obvious; however, many surface water features, such as streams, lakes, and wetlands, interact with groundwater in some way. Thus, the development or contamination of one may affect the other. An understanding of the basic principles of interactions between groundwater and surface water is therefore needed to effectively manage water resources.

In addition to sustaining base flow in a stream, groundwater can also quickly enter a stream in response to precipitation events. A single mechanism or a combination of mechanisms, such as the magnitude of the precipitation event, antecedent soil-moisture conditions, soil hydraulic properties, water table depth, and/or capillary fringe length (Sophocleous 2002; Hudak 2005), may contribute to stream-flow response to a precipitation event. Translatory flow, macropore flow, groundwater ridging (or capillary fringe groundwater ridging), and return flow are some of the mechanisms by which groundwater may enter a stream in response to a precipitation event (Sophocleous 2002; Kirchner 2003; Cloke et al. 2006). Groundwater may discharge directly into a stream channel or enter a channel as overland runoff.

A groundwater investigation in the WHC Sub-watershed was initiated in 2009 as groundwater appeared to be a potential contributor to surface water flow. The goal of the groundwater work was to understand the physical and chemical characteristics of groundwater in the WHC Sub-watershed. The focus was on the shallow groundwater environment. The work conducted in 2009 and 2010 was a partnership between Alberta Agriculture and Rural Development (ARD) and Dr. Gary Kachanoski's research group with the Department of Renewable Resources at the University of Alberta. The work was continued in 2011 and 2012 by ARD.

4.5.1 Methods

4.5.1.1 Well Instrumentation

Monitoring wells were installed in and around the WHC Sub-watershed from August to December 2009. Installations were led by staff from the Department of Renewable Resources at the University of Alberta. Seventeen groundwater monitoring nests were installed within the WHC Sub-watershed with an additional 10 nests installed to the east between the sub-watershed and Lacombe Lake (Figure 4.24). Groundwater nests were installed at most of the BMP sites, with the exception of the NFD site, using a Geoprobe© 7730DT (Figure 4.25a). The majority of nests included one water table well (threaded 25.4-mm diameter PVC pipe) and two piezometers (19.1-mm diameter polyethylene tubing) (Figure 4.26). However, if bedrock was predicted to be shallow, only one piezometer was installed. Piezometers were installed adjacent to the water table wells with an approximate distance of 1 m between wells. The depths of water table wells ranged from 3.5 to 4.0 m below ground surface (bgs), while the piezometers ranged from 4.5 to 17.0 m bgs. For the water table wells, pre-washed filter sand (Sil-7; 20/50 mesh; Sil Industrial Minerals, Alberta, Canada) was added around the wells to about 0.2 m above the screened area. Powdered bentonite (NaturalGel) was added on top of the sand up to 0.5 m below the ground surface to seal the void around the well.

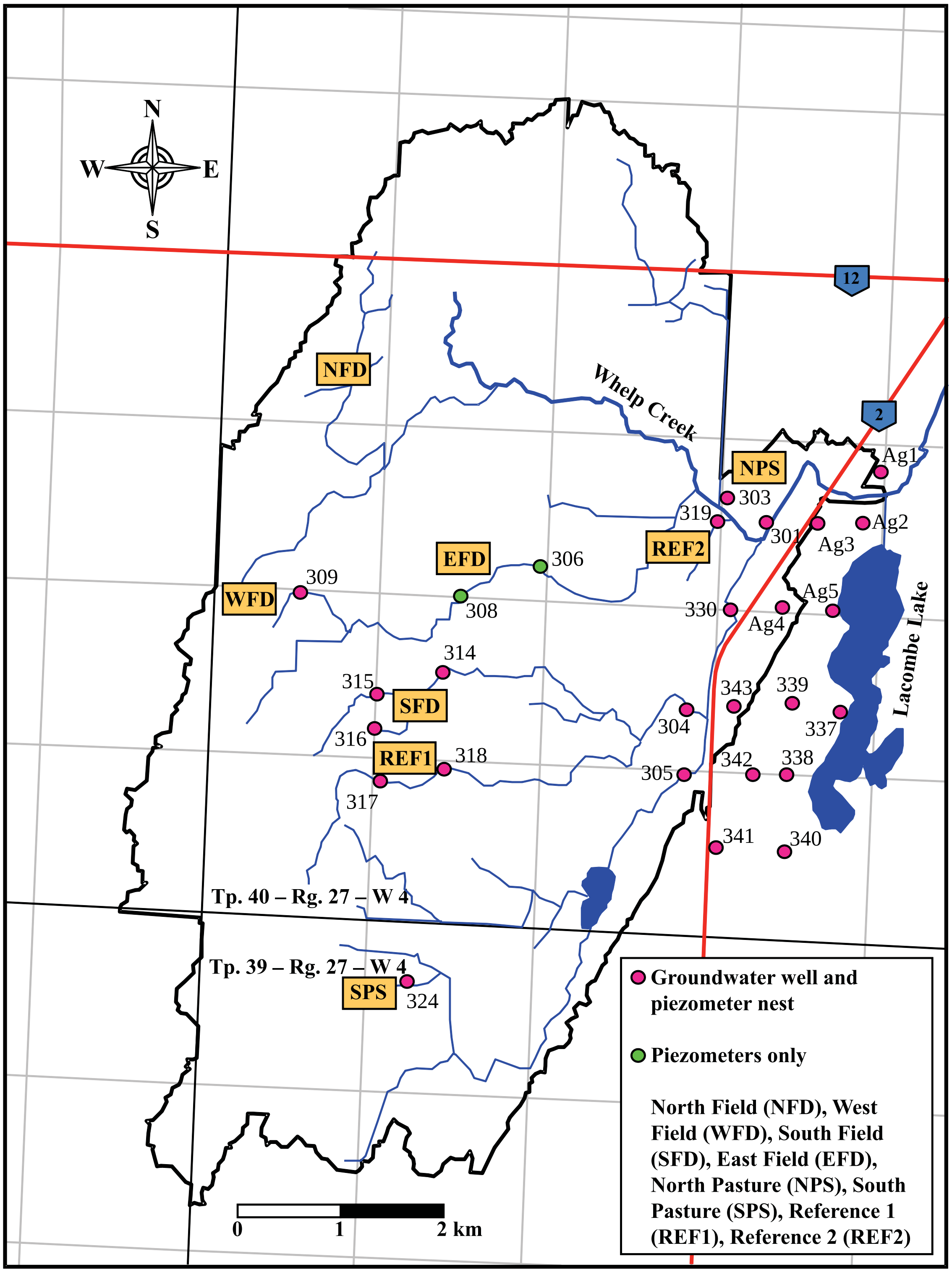

Figure 4.24. Location of groundwater nests in and around the Whelp Creek Sub-watershed. All but two nests at the East Field (EFD) included one water table well and two piezometers. Nests at the EFD site included only one piezometer.

The piezometer screens (Figure 4.25b) were wrapped with Polypropylene Spectra/mesh (PP) at 210 µm (Spectrum Labs, California, United States) and secured with a self-adhesive alkaline resistant fiberglass drywall tape (Fiba Tape, United States) (Figure 4.25c). The Sil-7 filter sand was added around the piezometer screens. Granular bentonite (Enviroplug No. 20 sodium bentonite; Wyo- Ben, Wyoming, United States) was then added to about 0.5 m from the surface. The top 0.5 m of the void around the piezometer was filled with powdered bentonite to ensure a quick seal.

At the selected BMP and watershed-wide sites, well nests were installed in association with a surface water monitoring station (e.g., Station 301). The wells were identified with the same number as the station followed by an A, (water table wells), B, or C (piezometers) (e.g., 301A, 301B, 301C). Together at a site, the water table well and piezometers were referred to as a nest (e.g., Nest 301). Collectively, the surface water monitoring stations and nests were referred to as sites (e.g., Site 301).

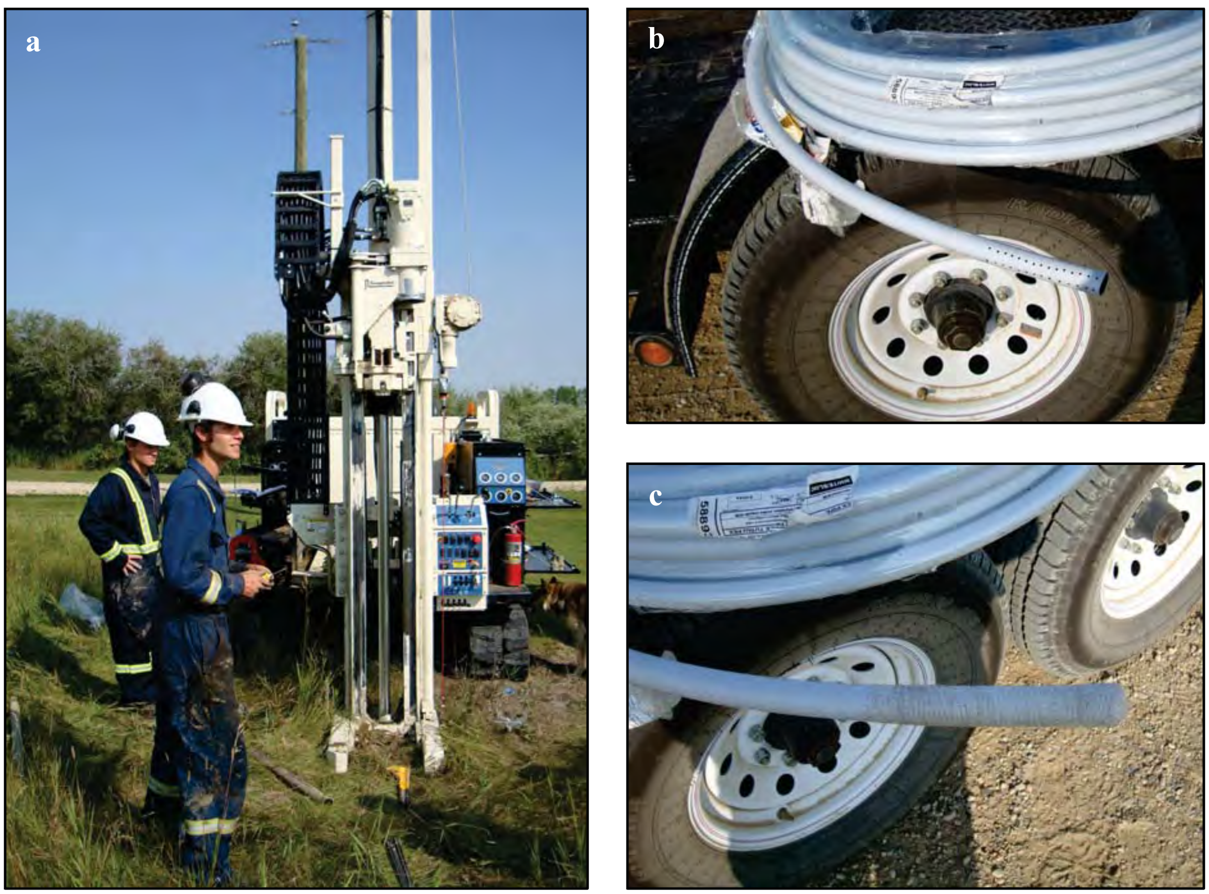

Figure 4.25. Installation of groundwater wells using a (a) Geoprobe© 7730DT and polyethylene tubing for the piezometers with (b) screen holes (2-mm diameter, 10 mm apart, in six rows) and (c) and mesh covering.

4.5.1.2 Well Development and Well Elevation Surveying

In order to remove fine particles from around the well screen, improve the rate of recharge to the well, and stabilize the aquifer to produce more representative samples, wells were developed (i.e., bailed) from October 2009 to February 2010. Water was removed from each well using a bailer (Solinst, Canada) until two times the standing water volume was removed. In the case of slow recharge rates, the wells were bailed until dry. Well elevation and location were measured and recorded using a Thales ZMax GPS unit (±0.05-m vertical accuracy).

4.5.1.3 Groundwater Monitoring

Groundwater elevation. Water levels were recorded using a water-level meter with depth sounder (Solinst model 102, Canada). Continuous water-level measurements were obtained in the water table well at the outlet (Well 301A) of the sub-watershed using a Level TROLL® (in-Situ Inc., Fort Collins, Colorado, United States) (Figure 4.27).

Contour plots used to illustrate horizontal groundwater flow direction were prepared using Surfer 9 (Version 9.2.397 ©1993-2009. Golden Software, Inc., Golden, Colorado, United States). Contours were prepared with grids generated using the Kriging method of interpolation.

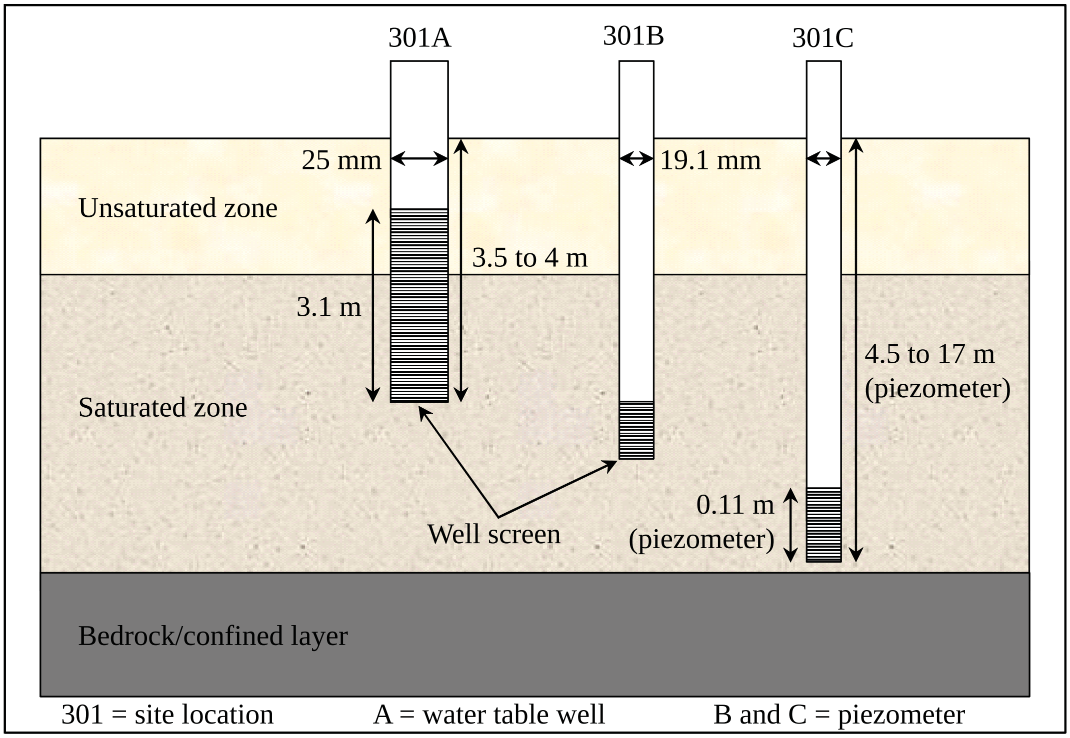

Figure 4.26. Schematic diagram of water table well (301A) and piezometers (301B and 301C) installations at a typical nest site. Wells were approximately 1 m apart.

Groundwater purging, sampling, and analysis. Groundwater samples were collected every other week in March and April 2010, monthly from May to November 2010, four times a year in 2011 to capture seasonal effects, and in winter and spring 2012. Water table wells were purged and then sampled 2 d later. Dedicated bailers (Solinst, Canada) were left inside each water table well and used for purging and sampling. Prior to purging, the dedicated bailer was removed from the well, the contents of the bailer poured back into the well, and the water level measured using a water level meter with depth sounder (Solinst model 102, Canada). During purging events, water levels were recorded for the water table wells and piezometers when possible. However, the piezometers were only used for water-level measurements, not for groundwater sampling. Water table wells were purged by removing a minimum of two times the standing well volume or until the well was dry. Sampling included collection of field measurements and groundwater samples. Field measurements (pH, EC, temperature) were made in a sample bottle using the first bail from the well. Sample bottles were triple rinsed with well water before filling. One, 1-L high-density polyethylene bottle was filled with as little headspace as possible for chemical analysis. In 2010 only, one, 200-mL sample bottle containing sodium thiosulphate preservative was used for bacterial analysis. Two to three, 1-L duplicate samples were collected during each sampling event for quality control purposes. All samples were packed on ice in a cooler and shipped overnight to the appropriate laboratory for analysis.

Groundwater samples were analyzed for NO_3-N, Cl, NH_3-N, TN, TDP, TP, total coliforms (2010 only), and *E. coli* (2010 only) (Table 4.13). Other parameters were also analyzed (calcium, magnesium, sodium, potassium, sulphate, bicarbonate, carbonate, nitrite nitrogen, and orthophosphate) but are not presented in this report.

All groundwater data were validated to ensure fractions of N and P did not exceed the totals (TN and TP) and that individual samples met the principle of electrical neutrality. Parameter concentration values that were less than the measurable method detection limit (MMDL) were given a value half the MMDL.

Figure 4.27. Measuring groundwater level using (a) a Level TROLL® at Station 301 (outlet) and (b) a water level meter with depth sounder at Station 317 (Reference 1 site).

Table 4.13. Procedures used for nitrate nitrogen and chloride analysis for groundwater samples.

Analytical parameter[z]	Sample preservation	Measurable method detection limit[z]	Analtical method[y]
nitrate nitrogen	chill to 4°C	0.10 mg L^{-1} ± 5%	CFA[x]
chloride	chill to 4°C	0.28 $mmol_c$ L^{-1} ± 5%	CFA
Total coliforms	$Na_2S_2O_3$	nd[w]	membrane filtration
Escherichia coli	$Na_2S_2O_3$	nd	membrane filtration

[z] Nitrate nitrogen and chloride was analyzed by Alberta Agriculture and Rural Development, Lethbridge, Alberta; total coliforms and *Escherichia coli* were analyzed by the Provincial Laboratory for Public Health, Calgary, Alberta.
[y] From Eaton et al. (1995).
[x] CFA = air-segmented continuous-flow analysis.
[w] nd = no detection.

4.5.1.4 Groundwater Data Analysis

Not all data from every well were used in data interpretations and statistical analyses. Water-level measurements from all water table wells were used to determine groundwater flow directions, while only data from water table wells within the WHC Sub-watershed were used to compare groundwater and surface water quality. Furthermore, groundwater data from some wells were not used in interpretations or done so with caution. These wells were excluded due to uncertainty around well integrity and the collection of representative groundwater samples. It was questionable whether the bentonite around wells at Nests 305, 315, 318, and 330 properly sealed the wells (i.e., well or casing moved). Furthermore, surface water had pooled after heavy rainfall at Nests 304, 305, 314, and 319 and was very close to or above the top of the wells in 2010 and/or 2011. It was assumed that surface water intrusion had occurred at these wells, and interpretations were done with caution.

All statistical analyses were computed in SYSTAT 11 (SPSS Inc. 2004). Groundwater data were also compared to drinking water quality guidelines and aesthetic objectives for NO_3-N and Cl, respectively (Health Canada 2012). Shallow groundwater in the region is not used for human consumption; however, the Canadian Drinking Water Quality Guidelines were used for comparison purposes.

Vertical hydraulic gradients were calculated for adjacent wells in each nest in the WHC Sub-watershed using water-level measurements for representative dates in 2010. The direction of groundwater movement was determined by dividing the change in head (water level) by the distance between two well screens. Vertical gradients were calculated by using the distances from a combination of the top, middle, and bottom of the screens (USEPA 2013b; Figure 4.28). If the water level was below the top of the screen in a water table well, the submerged length of the screen was used in the calculations. Vertical gradients were determined by averaging values for the top, middle, and bottom screen distances.

4.5.1.5 Leaching Profiles

Soil cores were collected using a B30 drilling rig with a 1.9-cm core barrel at the REF2, EFD, and NFD sites in fall 2009, and again in fall 2010 at the EFD and REF2 sites when the remaining BMP field sites (SFD, WFD, and REF1) were sampled. Cores were collected in conjunction with

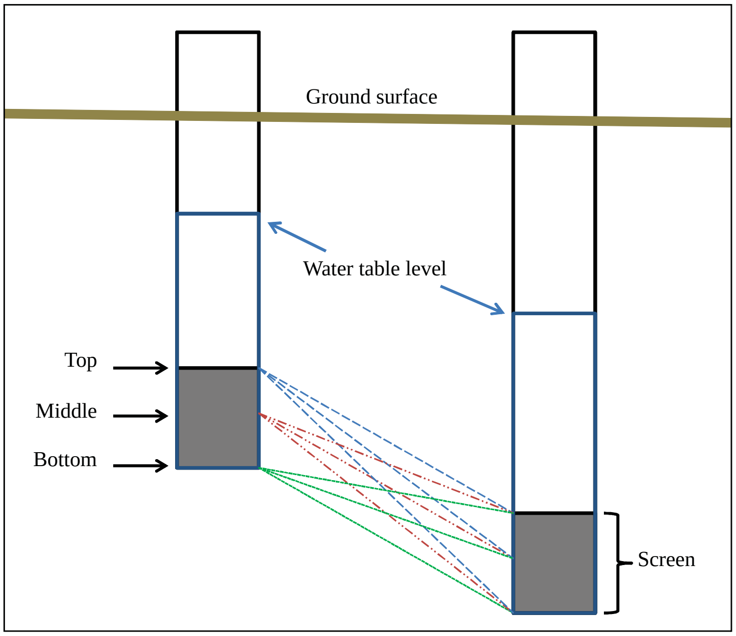

Figure 4.28. Range of possible gradients between the top, middle, and bottom of two well screens as used to calculate vertical hydraulic gradients.

agronomic soil sampling at these sites. Only the 2009 data for the EFD site and the 2010 data for the REF2 site were used to compare to the other four sites. Samples were analyzed for extractable NO_3-N and ammonium nitrogen (NH_4-N), extractable soil-test phosphorus (STP), and Cl. Further details about deep-core soil sampling are in Sub-section 2.9.4.

4.5.1.6 Hydrograph Analysis

Hydrograph analysis was conducted to estimate the contribution of base flow, or groundwater discharge, to the total flow at the sub-watershed outlet (Station 301). The average daily surface water flow data at Station 301 from 2010 to 2012 and the automated Web-based Hydrograph Analysis Tool (WHAT; Lim et al. 2005) were used for the analysis. This online tool minimizes the inconsistent and subjective results often obtained using manual techniques for separation of base flow from stream flow. The Eckhardt filter was used to separate high frequency waves from low frequency waves, which are associated with direct runoff and base flow, respectively. The Eckhardt filter has been found to match base flow from manual separation as well as measured base-flow values (Lim et al. 2005). The Eckhardt filter uses a Base Flow Index (BFI), and the recommended BFI_{max} of 0.5 for ephemeral streams with a filter parameter value of 0.98 was used in order to remove subjective influence. Note that the BFI_{max} value was for ephemeral streams with porous aquifers. No other values were recommended for ephemeral streams. Although the Burried Red Deer River Valley and Gull Lake meltwater channel are primarily gravel aquifers, surficial deposits in Lacombe County consist of glacial till or pre-glacial sand, silt, and clay and are not likely as porous as predicted in the model. Also, WHAT cannot account for external factors that may affect a stream hydrograph, such as reservoir releases and snowmelt.

4.5.2 Results and Discussion

4.5.2.1 Shallow Groundwater Levels and Flow Direction

Groundwater levels in the water table wells ranged from 0.03 to 4.12 metres below ground surface (m bgs) from 2010 to 2012, with annual averages ranging from 1.16 m bgs in 2011 to 2.20 m bgs in 2010 (Table 4.14). Thus, groundwater levels were on average 1.0 m higher in 2011 than 2010, and ranged from 0.5 to 1.8 m higher (Table 4.14). These findings were consistent with the range of water level measurements for Lacombe County reported by Hydrogeological Consultants Ltd. (2001). Annual differences in groundwater levels in the watershed were influenced by total annual precipitation in the area. Total annual precipitation was highest in 2010 (Sub-section 4.2.2), and this likely recharged shallow groundwater and caused the higher groundwater levels measured in 2011. It was determined that shallow groundwater moved from west to east across the WHC Sub-watershed (Figure 4.29).

Shallow groundwater levels also fluctuated seasonally. The water table was shallowest in the summer months, particularly in July 2010 and 2011, and deepest in the winter months (Table 4.15). Groundwater levels measured in Well 301A near the outlet of the watershed started to rise in May and peaked in July or August in 2010 and 2011 (Figure 4.30). The rise in the groundwater levels during the spring and summer may have been attributed to recharge from spring and early summer precipitation (April through July), which was 1.25- to 2-fold higher in 2010 through 2012 compared to the 30-yr averages (Sub-section 4.2.2). After initial recharge in May 2012, groundwater levels slowly decreased rather than peaking in the summer, though levels were still high from the ample precipitation received from March through June. This was a result of lower precipitation in July 2012 compared to 2010 and 2011 and the 30-yr average (Sub-section 4.2.2). The low water level in the winter and early spring (March and early April) was a result of no recharge to the groundwater when the ground was frozen.

Table 4.14. Statistical summary of measureable depth to shallow groundwater for water table wells within the Whelp Creek Sub-watershed from 2010 to 2012.

Statistic	2010[z,y]	2011[z,y]	2012[z,y]
Number of samples	137	125	28
Minimum (m bgs)[x]	0.34	0.03	0.20
Maximum (m bgs)	4.12	3.47	3.23
Median (m bgs)	2.12	1.14	1.60
Average (m bgs)	2.20	1.16	1.55
Standard deviation (m bgs)	0.86	0.73	0.76

[z] Measurements could not be made when groundwater levels were below the bottom of the well screen; dates when this occurred were omitted from the calculation.
[y] Water level measurements were taken from March to November 2010, February to November 2011, and January to May 2012.
[x] m bgs = metres below ground surface.

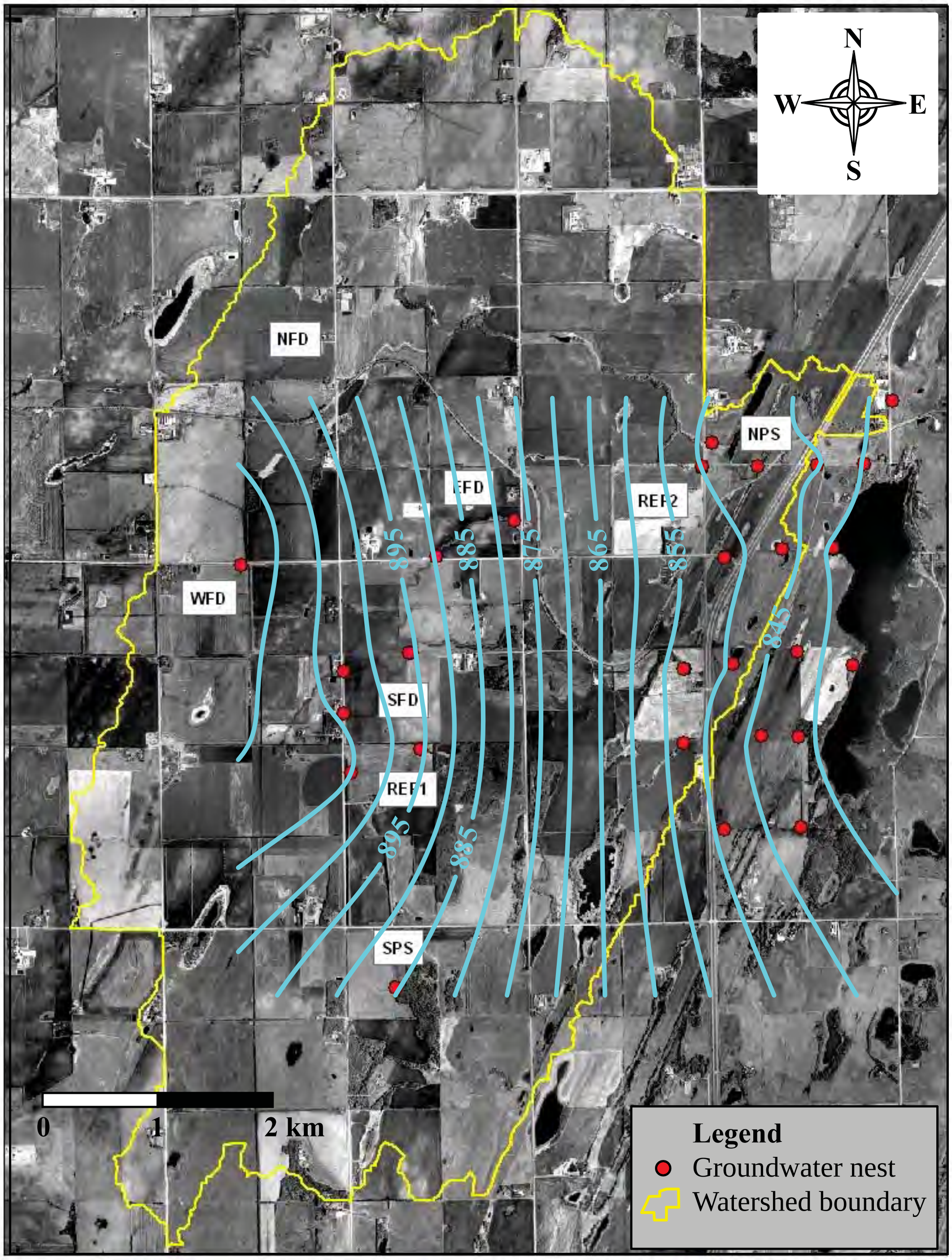

Figure 4.29. Groundwater elevations (metres above sea level) calculated from water table well measurements on July 7, 2010. Direction of flow was from high to low elevation (i.e., from west to east).

Table 4.15. Average depth to shallow groundwater in 2011 by season for four water table wells in the Whelp Creek Sub-watershed.

Well	Winter[z] (n)[y]	Spring[z] (n)	Summer[z] (n)	Fall[z] (n)
	--------------------------------	(m bgs)[x]	--------------------------------	
301A	1.96 (1)	1.31 (4)	0.95 (4)	1.45 (3)
303A	1.53 (1)	1.09 (4)	0.67 (1)	1.37 (1)
309A	2.53 (1)	1.41 (5)	0.63 (3)	1.34 (3)
324A	2.07 (1)	1.40 (4)	1.12 (3)	1.51 (2)

[z] Winter = Jan. to Mar., Spring = Apr. to Jun., Summer = Jul. to Sep., Fall = Oct. to Dec.
[y] n = number of water level measurements.
[x] m bgs = metres below ground surface.

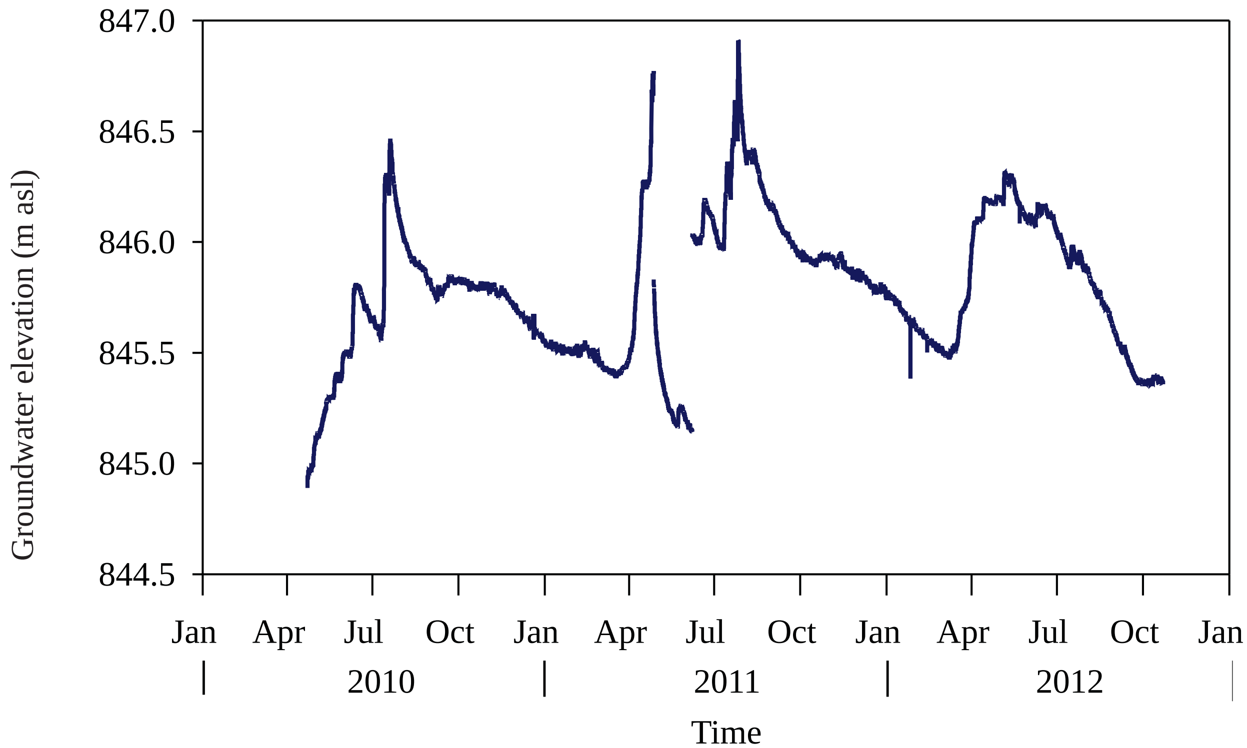

Figure 4.30. Shallow groundwater elevation in metres above sea level (m asl) in water table Well 301A from 2010 to 2012.

In addition to annual and seasonal changes, groundwater levels differed among the water table wells depending on where in the watershed they were located. Groundwater levels in individual wells in the WHC Sub-watershed changed by 0.3 to 3.0 m (Table 4.16). Water levels in many of the water table wells were around 3.5 m bgs; however, wells at the SFD (Wells 314A to 316A) and REF1 (Wells 317A and 318A) sites were often dry, even in 2011 when the water table was shallowest. Shallow groundwater appeared to be influenced more by precipitation events in the eastern portion of the sub-watershed and near the outlet than in the west and southern portions.

Not surprisingly, vertical hydraulic gradients differed by location in the watershed and by depth. An upward (positive) vertical gradient was generally observed in groundwater nests in the eastern portion of the sub-watershed, closer to the outlet (Table 4.17). A downward (negative) vertical gradient was generally observed in the western and southern portions of the sub-watershed. Wells at the outlet were always discharging (upward) or had no vertical gradient, regardless of the time of year. Despite observations of prolonged surface water flow and discharging springs in the trees to the south of REF1 (Site 319), the upper zone had a downward vertical gradient. The only upward vertical gradient at Site 319 was observed between the deepest and shallowest wells.

Table 4.16. Statistical summary of measureable depth to shallow groundwater for water table wells within the Whelp Creek Sub-watershed.

Well[z]	Minimum	Maximum	Median[y]	Average[y]
	------------------------------- (m bgs)[x] -------------------------------			
301A	1.6	3.1	2.8	2.5
303A	1.2	3.6	2.1	2.0
304A	0.8	3.4	3.3	2.6
305A[w]	0.9	3.2[v]	2.0	2.0
309A	1.2	4.1[v]	2.0	2.5
314A	1.7	3.5[v]	3.4	3.1
315A[w]	0.8	2.1[v]	2.1	1.8
316A	1.6	3.6[v]	2.6	2.6
317A	1.3	3.5[v]	2.1	2.3
318A[w]	1.9	2.2[v]	2.2	2.1
319A	0.3	2.8	1.1	1.1
324A	1.7	3.4	2.1	2.2
330A[w]	1.4	2.9	2.1	2.1

[z] A represents the water table well.
[y] Measurements could not be made when groundwater levels were below the bottom of the well screen; dates when this occurred were omitted from the calculation.
[x] m bgs = metres below ground surface.
[w] Well seal may have been compromised. Use caution when interpreting data from these wells.
[v] Well was dry on at least one sampling date.

The geologic composition of surface and subsurface soil affects the location and rate of groundwater recharge and discharge. High ground west of the Red Deer area generates groundwater flow systems of local to regional scales (Le Breton 1971). Several springs, sloughs, and wetlands were observed in the WHC Sub-watershed and are physical indicators of groundwater interaction with the surface landscape. Wetlands are often present in landscapes that receive groundwater discharge, though wetlands can also receive and store surface runoff.

Recharge and discharge can occur below the ground surface between different aquifers (i.e., an unconfined surficial aquifer and a confined bedrock aquifer). A regional study showed that surficial deposits recharge (downward hydraulic gradient) the underlying bedrock aquifers in much of Lacombe County; however, there appears to be more discharge (upward hydraulic gradient) from the bedrock aquifers to the surficial deposits throughout most of the WHC Sub-watershed (Hydrogeological Consultants Ltd. 2001). The upward hydraulic gradient is specifically observed in and near bedrock lows, such as the Burried Red Deer River Valley, and this is consistent with the location of the outlet in the current study (Figure 4.31). The Buried Red Deer River Valley and Gull Lake meltwater channel are in the bedrock lows in the northern and eastern parts of the WHC Sub-watershed and yield higher volumes of groundwater. The southern portion of the watershed contains bedrock highs, or upland areas, which generally experience lower groundwater yields (Hydrogeological Consultants Ltd. 2001).

Table 4.17. Vertical hydraulic gradients for selected sites in the Whelp Creek Sub-watershed on three dates in 2010.

	March 2, 2010		June 7, 2010		October 12, 2010	
Well pair	Average vertical hydraulic gradient	Direction of vertical groundwater movement	Average vertical hydraulic gradient	Direction of vertical groundwater movement	Average vertical hydraulic gradient	Direction of vertical groundwater movement
301A-301B	-0.04	Upward	-0.03	Upward	-0.03	Upward
301A-301C	-0.11	Upward	-0.08	Upward	-0.10	Upward
301B-301C	-0.02	Upward	0.00	No gradient	-0.01	Upward
303A-303B	0.00	No gradient	0.00	No gradient	0.00	No gradient
303A-303C	0.03	Downward	0.03	Downward	0.03	Downward
303B-303C	-0.01	Upward	-0.01	Upward	-0.02	Upward
309A-309B	27.95	Downward	0.60	Downward	2.08	Downward
309A-309C	5.30	Downward	1.39	Downward	-0.25	Upward
309B-309C	-0.03	Upward	1.41	Downward	-0.02	Upward
315A-315B	0.02	Downward	0.02	Downward	1.01	Downward
315A-315C	0.01	Downward	0.01	Downward	0.87	Downward
315B-315C	0.10	Downward	0.10	Downward	1.92	Downward
319A-319B	0.21	Downward	0.27	Downward	0.01	Downward
319A-319C	-0.03	Upward	-0.02	Upward	-0.05	Upward
319B-319C	0.29	Downward	0.43	Downward	0.10	Downward

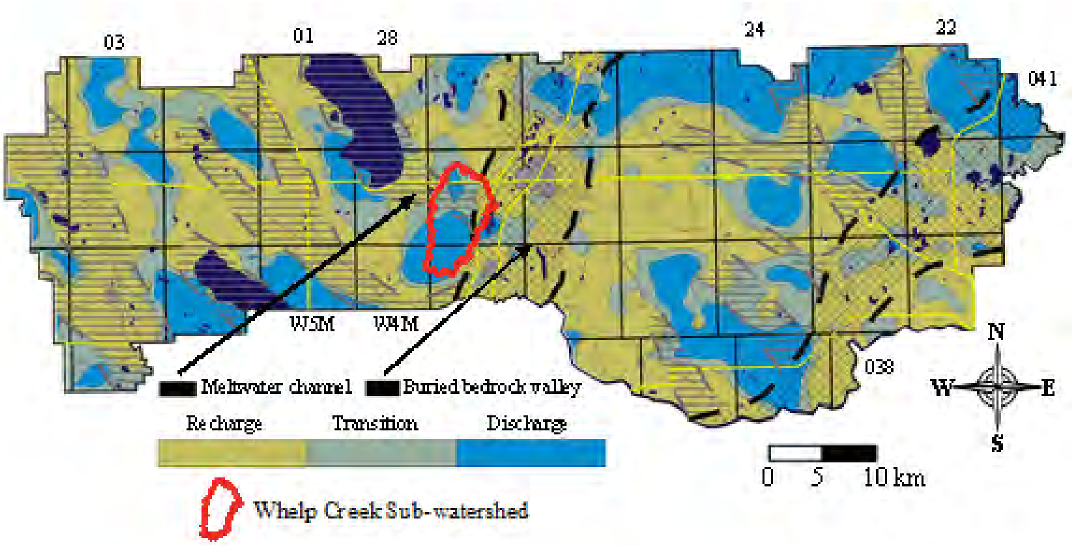

Figure 4.31. Recharge and discharge areas between surficial and upper bedrock aquifers in Lacombe County (Hydrogeological Consultants Ltd. 2001).

4.5.2.2 Groundwater Quality

Groundwater NO_3-N and Cl concentrations measured in the water table wells were generally low and did not exceed Canadian Drinking Water Quality Guidelines (Health Canada 2012). The concentration of NO_3-N ranged from 0.05 to 29 mg L^{-1} (Table 4.18), and only five of the 153 (3%) groundwater samples collected at 13 water table wells in the WHC Sub-watershed were above the NO_3-N drinking water quality guideline of 10 mg L^{-1} (Figure 4.32). The samples that exceeded the guideline were measured in one well (Well 303A) in August, September, and October 2010 and April and May 2011. Nitrate N generally occurs at low concentrations in groundwater, and levels greater than 3 mg L^{-1} are considered to be caused by anthropogenic sources (Madison and Brunett 1985), with the exception of geologic nitrate (Hendry et al. 1984; Rodvang and Simpkins 2001; Rodvang et al 2002). Although the average NO_3-N concentration measured in the shallow groundwater was low (1.55 mg L^{-1}), NO_3-N concentrations greater than 3 mg L^{-1} were measured in four wells (304A, 314A, 316A, 317A) in addition to Well 303A. The elevated NO_3-N concentrations were only measured in spring 2011 and/or spring 2012. Note that surface water intrusion may have affected water quality in Wells 304A and 314A when surface water pooled above the tops of the wells.

Chloride concentrations measured in the shallow groundwater ranged from 5 to 379 mg L^{-1} (Table 4.18), and only three of the 153 (2%) groundwater samples were above the aesthetic drinking water quality guideline of 250 mg L^{-1} (Figure 4.32). Shallow groundwater with Cl concentrations greater than 10 to 20 mg L^{-1} may be from anthropogenic sources (Forrest et al. 2006).

Table 4.18. Statistical summary of groundwater chemistry for water table wells within the Whelp Creek Sub-Watershed from 2010 to 2012.[z]

Statistic[y]	Cl	NO_3-N	NH_3-N	TN	TDP	TP
Number of samples	153	153	153	152	153	152
Minimum (mg L^{-1})	4.96	0.05	0.05	0.25	0.01	0.02
Maximum (mg L^{-1})	379	29.4	0.35	31.1	0.75	3.92
Median (mg L^{-1})	16.6	0.21	0.05	0.74	0.01	0.18
Average (mg L^{-1})	28.2	1.55	0.07	2.12	0.02	0.41
Standard deviation (mg L^{-1})	56.1	3.87	0.05	4.09	0.08	0.61

[z] Cl = chloride, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TN = total nitrogen, TDP = total dissolved phosphorus, TP = total phosphorus.
[y] Data are from Wells 301A, 303A, 304A, 305A, 309A, 314A, 315A, 316A, 3 17A, 318A, 319A, 324A, and 330A.

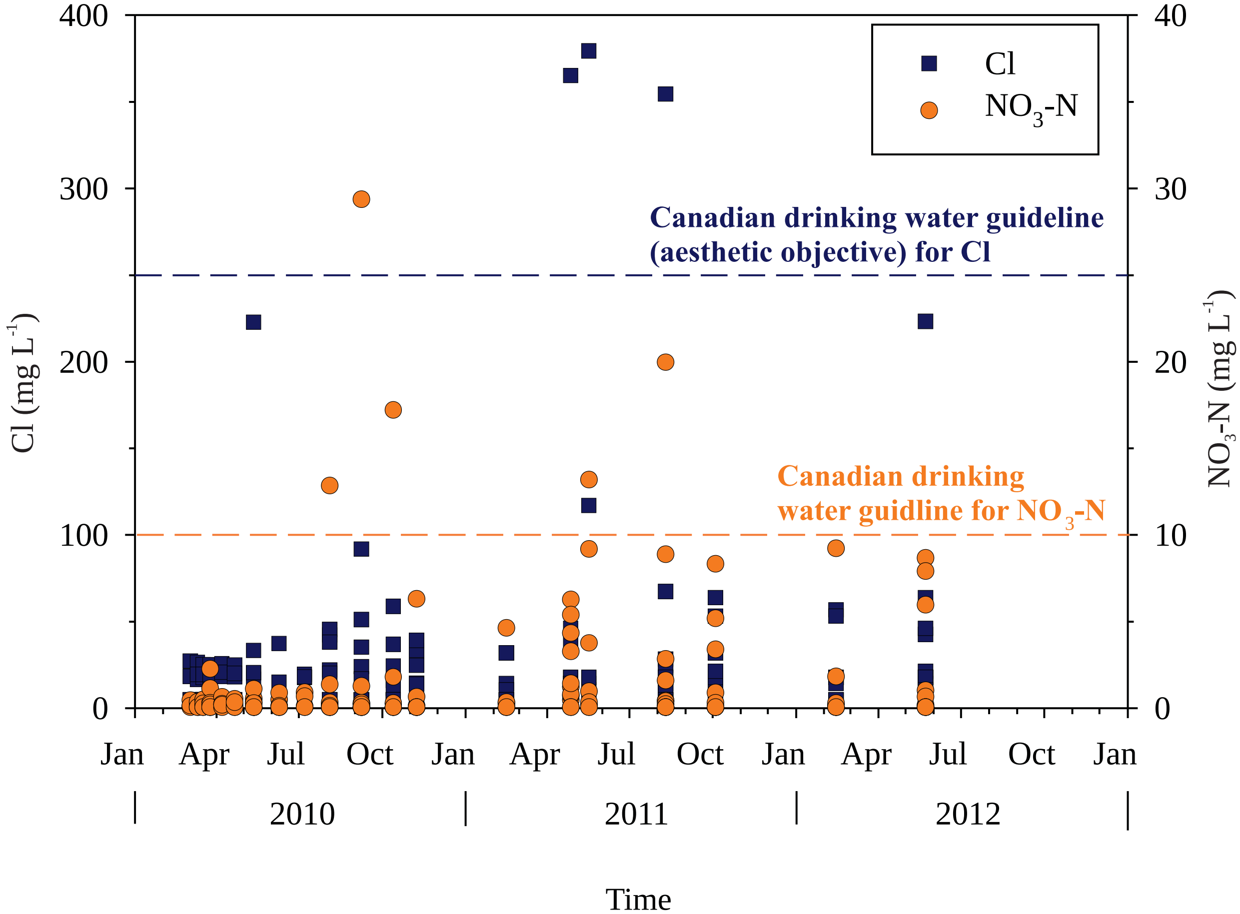

Figure 4.32. Groundwater chloride (Cl) and nitrate nitrogen (NO_3-N) concentrations measured in wells located within the WHC Sub-watershed from 2010 to 2012.

Nitrate and Cl are highly soluble and can be indicators of manure contamination in groundwater. In particular, Cl does not undergo biological transformations or adsorb to soil and is considered to travel at the same rate as groundwater. It can therefore be used as a tracer or an indicator of manure contamination (Olson et al. 2002; Rodvang et al. 2004). The elevated Cl in Well 330A was not likely from manure as NO_3-N and other parameters such as potassium were very low and did not increase with Cl. The elevated concentrations of Cl and NO_3-N in Well 303A may indicate possible influence of manure application in the area. Chloride and NO_3-N were positively correlated for this well (r_s=0.835, P<0.01).

Overall, groundwater NO_3-N and Cl concentrations did not differ seasonally in the sub-watershed, and NO_3-N and Cl were not correlated. However, NO_3-N and Cl were positively correlated at the outlet (Well 301A, r_s = 0.688, P<0.01) and NPS (Well 303A, r_s = 0.835, P<0.01) sites.

Total N concentration ranged from 0.25 to 31 mg L^{-1} and TP concentration ranged from 0.02 to 3.9 mg L^{-1} (Table 4.18). On average, 73% of TN was in the form of NO_3-N; whereas, only 3% of TN was in the form of NH_3-N. About 5% of TP was in the form of TDP, suggesting that most of the P was particulate.

Escherichia coli were detected in 10% of all groundwater samples collected and were only found at two of the sites (Table 4.19). *Escherichia coli* were detected twice at the NPS site (Well 303A; once in July 2010 and once in September 2010) and once at the SPS site (Well 324A in September 2010). Cattle were present at both pasture sites when *E. coli* detections occurred. Total coliforms were detected in almost all samples collected in 2010. Total coliforms are commonly found in the environment as well as the intestines of mammals. Their detection, therefore, does not necessarily indicate the presence of fecal contamination.

4.5.2.3 Leaching profiles

The concentration of NO_3-N was the highest in the surface soil layer (0 to 30 cm) for five of the six sites (Figure 4.33). The one exception was the EFD. The concentration of NO_3-N was generally less than 5 mg kg^{-1} deeper than 30 cm for most of the soil profiles. The concentration of NO_3-N in the surface soil layer was highest at the NFD and NO_3-N concentration remained the highest with

Table 4.19. Summary statistics for total coliforms and *Escherichia coli* measured in shallow groundwater samples in the Whelp Creek Sub-watershed from March to November 2010.

Statistic	Total coliforms	*Escherichia coli*
Number of samples	31	31
Number of detects	29	3
Minimum (mpn 100 mL^{-1})	nd[z]	nd[z]
Maximum (mpn 100 mL^{-1})	>2420	120
Median (mpn 100 mL^{-1})	261	0
Average (mpn 100 mL^{-1})	759	5

[z] nd = not detected.

depth to the 210- to 240-cm layer compared to the other sites. The NFD received regular applications of dairy manure (Sub-section 4.7) and the higher concentrations and leaching with depth may have been the result of manure application. The soil profile at the NFD also had the highest concentration of Cl compared to the other five sites (Figure 4.34). Manure is a source of Cl, and the results in Figures 4.32 and 4.33 suggest net leaching of NO_3-N and Cl from applied manure. Field studies in southern Alberta have shown that the application of cattle manure can result in the accumulation and leaching of NO_3-N and Cl in soil (Chang and Entz 1996; Olson et al. 2003, 2009).

Prior to the deep-core sampling at the EFD in fall 2009, manure was last applied in fall 2007 (Sub-section 4.8). The field was then converted from annual cropping to alfalfa. Two years of alfalfa production likely resulted in the relatively low NO_3-N concentration in the 0- to 30-cm soil layer by fall 2009 (Figure 4.33). However, higher concentrations of NO_3-N occurred deeper in the soil profile, with maximum average values in the 150- to 210-cm layer. The average concentration of Cl also increased in the deeper soil layers at the EFD (Figure 4.34). These results also suggest possible leaching of NO_3-N and Cl from past manure application.

Average soil-test phosphorus (STP) ranged from 9 to 44 mg kg^{-1} in the 0- to 30-cm layer among the six sites. The two reference sites had the lowest STP concentration in the surface soil, with 12 mg kg^{-1} at REF1 and 9 mg kg^{-1} at REF2. Compared to the other four sites, the two reference sites had not received manure during the past several years. At all six sites, the concentration of STP decreased rapidly below 30 cm, and deeper than 120 cm, concentration remained low (1 mg kg^{-1}).

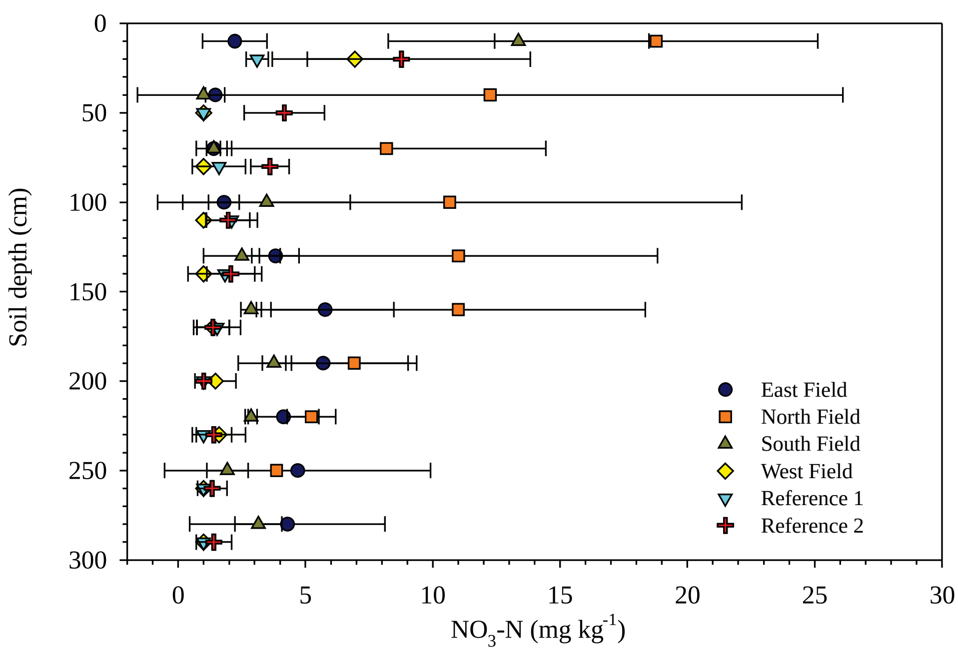

Figure 4.33. Average concentration of soil nitrate nitrogen (NO_3-N) in 30-cm increments at four BMP and two reference sites. Horizontal bars are standard deviations. Note that for each incremental layer, the East Field, North Field, and South Field data points are offset from the other three sites for clarity.

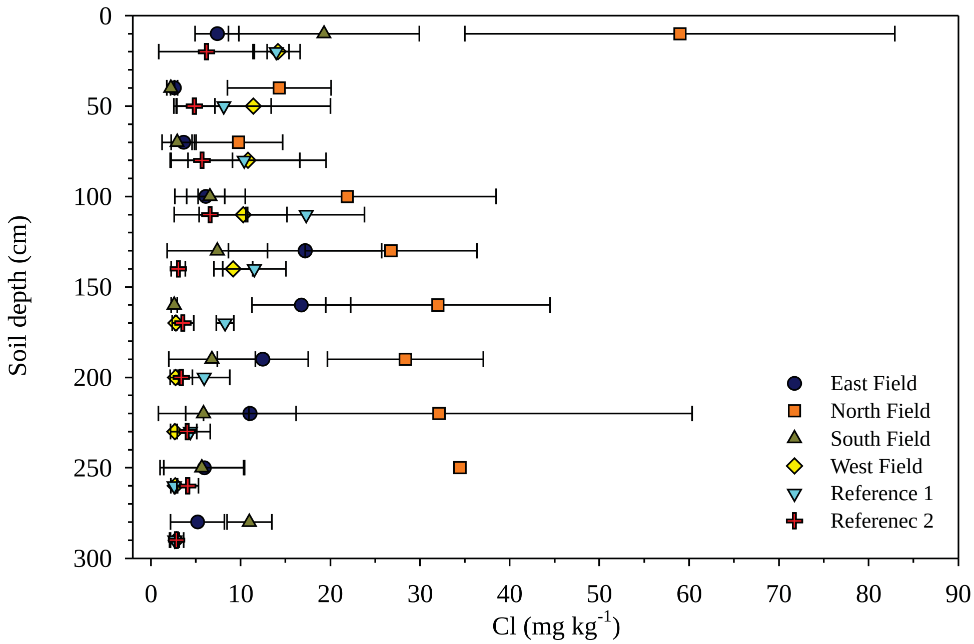

Figure 4.34. Average concentration of soil chloride (Cl) in 30-cm increments at four BMP and two reference sites. Horizontal bars are standard deviations. Note that for each incremental layer, the East Field, North Field, and South Field data points are offset from the other three sites for clarity.

4.5.2.4 Hydrograph Analysis of Base Flow Separation

Base-flow, or groundwater discharge, contributions to stream flow ranged from 0 to 100% and varied by year and time of year (Figure 4.35). Base flow contributed very little to stream flow during most events in May and most of June 2010. However, base flow prolonged stream-flow peaks after rainfall events in late June and July 2010. In 2011, base flow contributed during the majority of the open-water season (April to early November). Base flow accounted for less than half of stream flow in April 2011, and the majority of stream flow from May 2 to 22 and following large rainfall events in June, July, and August. Although overall stream volume and peaks were lower in 2012 than 2011, base flow contributions were similar in the two years. Overall, from 2010 to 2012, it was estimated that base-flow contributed 48% of total annual flow at the sub-watershed outlet on average. In 2010, the contribution from base flow was 38% and the contributions were similar in 2011 and 2012 at 50 and 51%, respectively. The lower base-flow contribution in 2010 was likely the result of the timing of precipitation events and a lower water table caused by drier conditions in 2008 and 2009 (Sub-section 4.2.2).

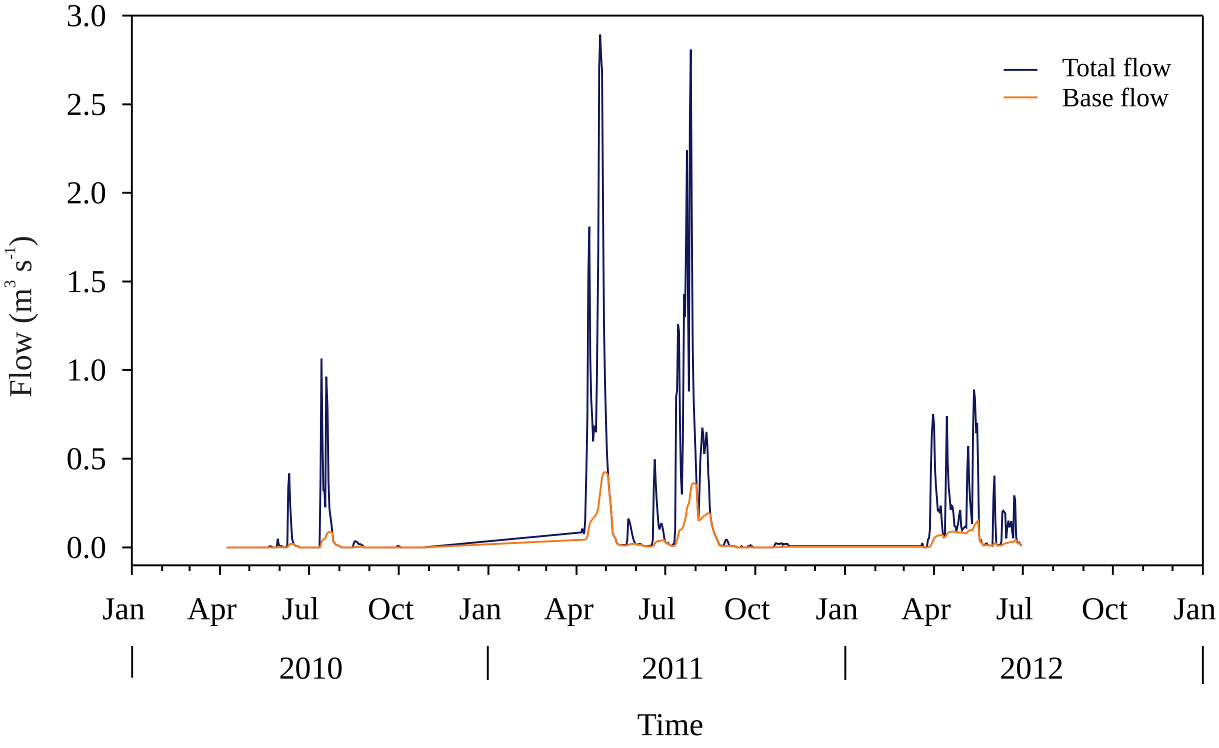

Figure 4.35. Total flow and base flow at the outlet (Station 301) of the Whelp Creek Sub-watershed from 2010 to 2012.

4.5.2.5 Groundwater and Surface Water Quality Comparisons

Groundwater and surface water concentrations are discussed below for Sites 301, 303, and 319 where groundwater discharge had the most potential to influence surface water among the monitored sites in the sub-watershed.

Groundwater NO_3-N and Cl concentrations were generally lower than surface water concentrations at the outlet (Station 301) and REF2 (Station 319) sites, and peak NO_3-N concentrations did not coincide with peak concentrations in surface water (Figures 4.36 and 4.37). Overall, concentrations of NO_3-N and Cl in groundwater changed very little with time in Wells 301A and 319A. In fact, concentration in Well 319A was often less than the MMDL values (Figure 4.37). In contrast, concentration values were more variable in surface water and the highest concentrations were in the summer months, generally from June through August when surface flows peaked during summer precipitation events. Therefore, any groundwater discharge near the outlet and REF2 areas likely did not contribute to the elevated surface water NO_3-N and Cl concentrations observed during the summer months. In fact, groundwater discharged to the surface would have caused a dilution effect in surface water.

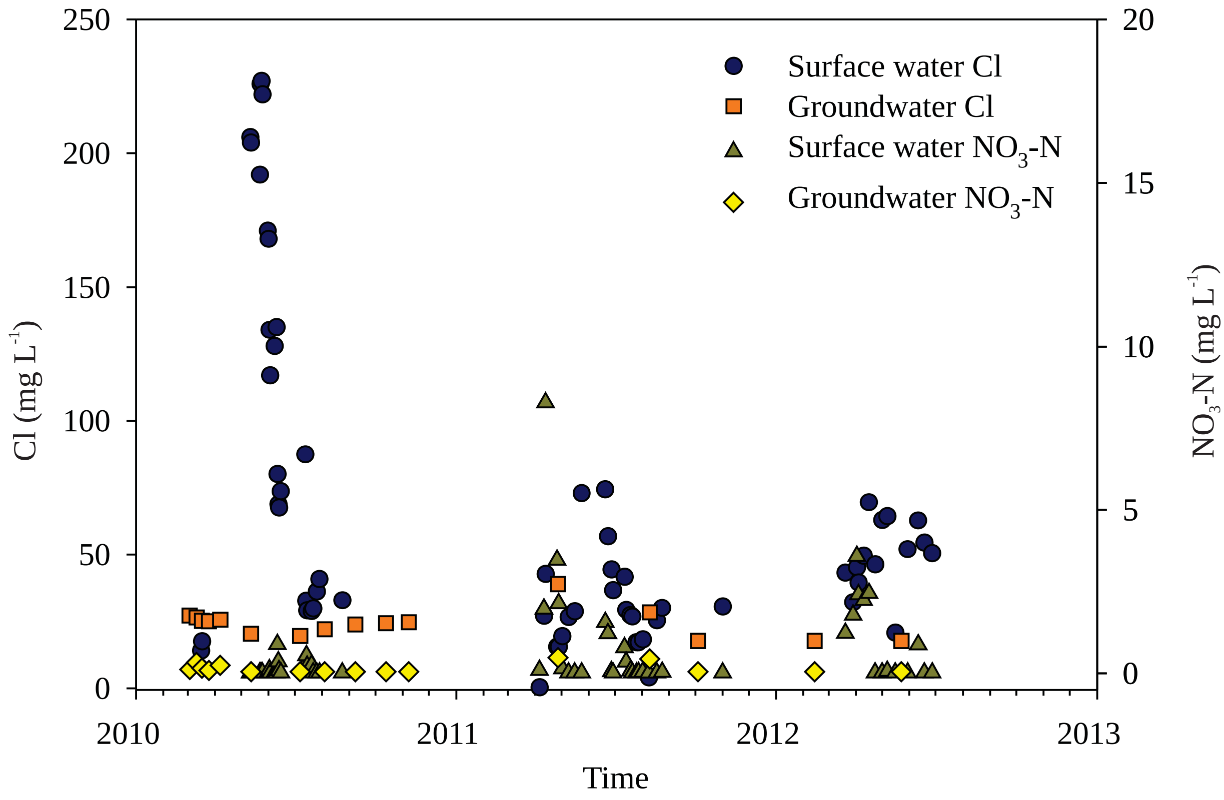

Figure 4.36. Groundwater and surface water nitrate nitrogen (NO_3-N) and chloride (Cl) concentrations measured at the outlet (Station 301) from 2010 to 2012.

In Well 303A, at the NPS site, the concentrations of NO_3-N and Cl were higher and more variable compared to Wells 301A and 319A. The average concentrations were 9.97 ±7.32 mg L^{-1} NO_3-N and 40.0 ±41.1 mg L^{-1} Cl in Well 303A. In comparison, average concentrations were 0.14 ±0.15 mg L^{-1} NO_3-N and 24.1 ±5.3 mg L^{-1} Cl in Well 301A, and 0.06 ±0.01 mg L^{-1} NO_3-N and <MMDL for Cl in Well 319A. In 2010, the concentrations of NO_3-N and Cl in groundwater were lowest and relatively consistent from March to July, followed by a large peak in concentrations during the August to October period (Figure 4.38). A similar patter occurred in 2011 with peak concentrations earlier in the year (May to August). A pattern could not be discerned in 2012 with only two sampling events.

In 2010, the increase in groundwater NO_3-N and Cl concentrations in Well 303A occurred after surface water flow stopped in WHC at Station 303, with the exception of a short flow period in October. Even though groundwater NO_3-N and Cl concentrations were much higher later in 2010, the elevated Cl concentration in the surface water measured in June and July was not caused by the influence of groundwater, which had relatively low Cl concentration during this period. From March to July 2010, the average concentration of NO_3-N was 0.36 mg L^{-1} in surface water and 0.60 mg L^{-1} in groundwater (Figure 4.38). Any groundwater discharged during this period may have slightly elevated concentrations in surface water.

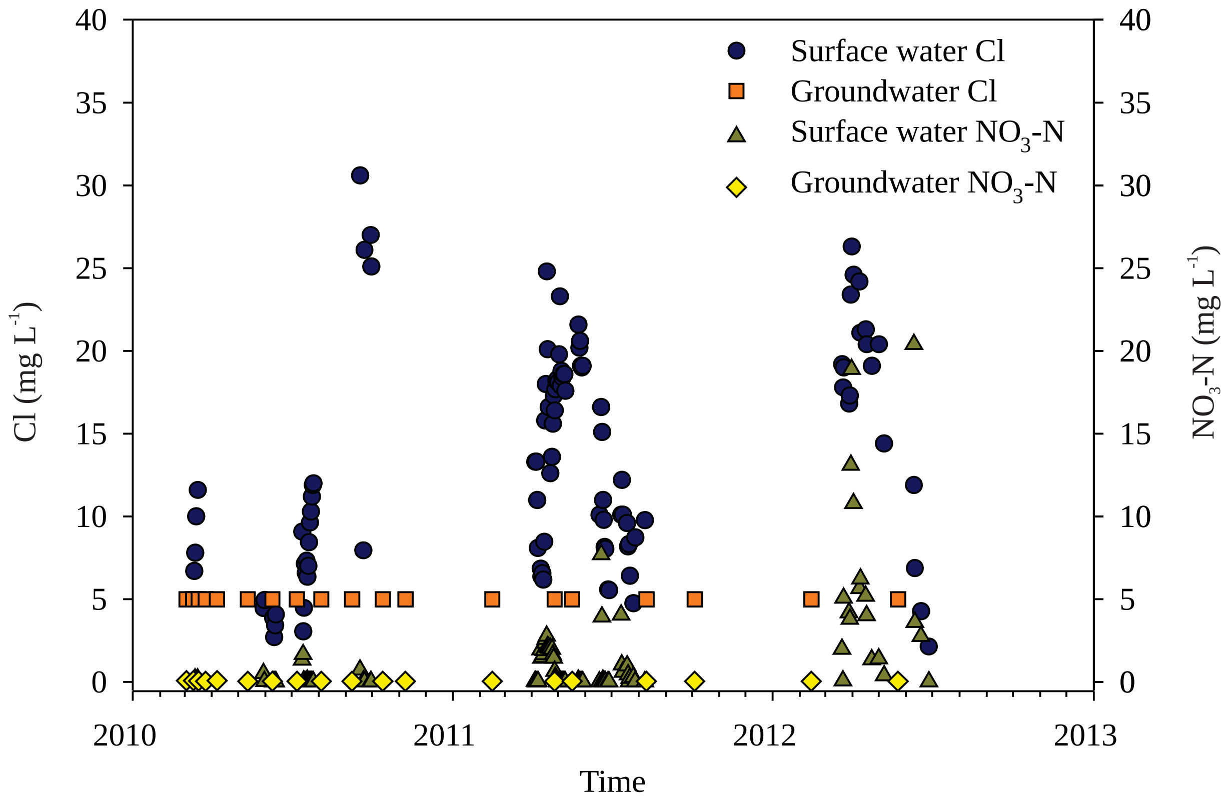

Figure 4.37. Groundwater and surface water nitrate nitrogen (NO_3-N) and chloride (Cl) concentrations measured at the Reference 2 site (Station 319) from 2010 to 2012.

In 2011 and 2012, high concentration of Cl in groundwater at Well 303A suggests that groundwater discharge into WHC increased Cl concentration in the channel (Figure 4.38). This was also likely true for NO_3-N in April 2011. After April 2011, the concentration of NO_3-N in the surface water at Station 303 was generally low (0.03 to 0.91 mg L^{-1}) compared to the higher concentrations in the groundwater (8.32 to 20 mg L^{-1}). This suggests that groundwater discharge had little if any influence on flow in WHC after April 2011. However, a NO_3-N concentration peak of 7.61 mg L^{-1} was measured in surface water on June 20, 2011. Surface water flow in WHC was more prolonged in 2011, and discharge of groundwater with higher concentrations may have contributed to the elevated Cl concentration and the NO_3-N concentration peak in surface water measured in June 2011 at Station 303. In 2012, groundwater, which had higher NO_3-N concentrations than surface water, may have influenced WHC early in the spring but not later in the year, as NO_3-N concentration decreased with time (Figure 4.38).

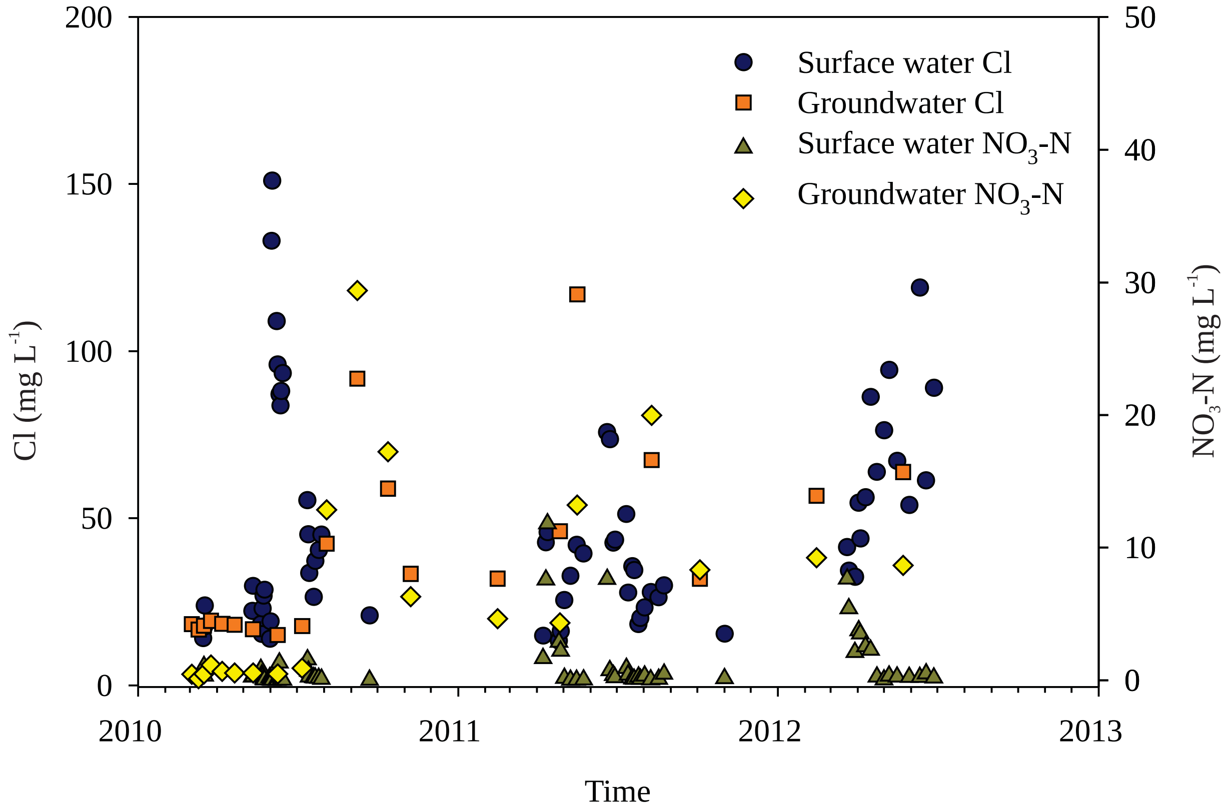

Figure 4.38. Groundwater and surface water nitrate nitrogen (NO_3-N) and chloride (Cl) concentrations measured at the North Pasture site (Station 303) from 2010 to 2012.

4.5.3 Conclusions

Shallow groundwater generally moved from west to east through the WHC Sub-watershed and varied seasonally, with levels generally starting to rise in May and peak in July or August. The rise in the shallow groundwater levels during the spring and summer may be attributed to recharge from spring and early summer precipitation. Low-water levels in the early spring may be attributed to no recharge to the groundwater when the ground was frozen. Shallow groundwater appeared to be influenced more by precipitation events in the eastern portion of the sub-watershed and near the outlet than in the west and southern portions. Also, an upward vertical gradient was generally observed in groundwater nests in the eastern portion of the sub-watershed, closer to the outlet; whereas, a downward vertical gradient was generally observed in the western and southern portions of the sub-watershed.

Average annual groundwater levels ranged from 1.16 to 2.20 m bgs in the sub-watershed from 2010 to 2012. Annual differences reflected the drier conditions in 2008 and 2009 and the wetter conditions in 2010 to 2011.

Shallow groundwater NO_3-N and Cl concentrations measured within the WHC Sub-watershed generally did not exceed Canadian Drinking Water Quality Guidelines and/or differ seasonally. Groundwater NO_3-N and Cl concentrations were generally similar to or lower than those measured in surface water within the WHC Sub-watershed. Groundwater concentrations of NO_3-N and Cl near the outlet did not contribute to the elevated surface water concentrations measured during the summer months. Groundwater discharge to the ground surface likely caused a dilution effect or prolonged surface flows with lower concentrations. However, there was some evidence at one well (Well 303A) where higher concentrations of NO_3-N and Cl in groundwater may have caused higher concentrations in surface water.

At two of six sites, there was evidence of NO_3-N and Cl leaching in the soil profile at depth of 1.5 to 2 m. The likely source of the NO_3-N and Cl was from manure application.

Base-flow, or groundwater discharge, contributions to stream flow ranged from 0 to 100%. It was estimated that base flow contributed 48% of total annual flow at the sub-watershed outlet on average from 2010 to 2012. The contribution of base flow was 38% in 2010 and about 50% in 2011 and 2012. The lower base-flow contribution in 2010 was likely the result of the drier conditions in 2008 and 2009.

4.6 West Field

4.6.1 Introduction and Hypotheses

The WFD site was one of four manure nutrient BMP sites established in 2008 (Sub-section 4.1.2). The field had a history of liquid hog manure application, but did not have an excess concentration of soil nutrients. Accordingly, the BMPs used at this site promoted optimal use of nutrients and a minimal loss of nutrients to surface runoff.

The BMPs were implemented in 2010 and included applying manure base on a nutrient management plan. Manure was applied in the spring as opposed to the fall in order to reduce nutrient loss in spring snowmelt. Also, manure was not applied within a setback zone along a drainage channel within the field.

These BMPs were chosen based on the assumptions that applying manure during fall without a nutrient management plan, and applying manure on a drainage pathway, would contribute dissolved nutrients to rainfall and snowmelt runoff at this site. The hypothesis was:

- Spring manure application based on crop P removal and using manure exclusion setbacks along the drainage channel would improve water quality parameters in runoff at the edge-of-field at this site.
  - It is expected that dissolved forms of nutrients will be reduced more than particulate forms.

4.6.2 Methods

4.6.2.1 Site Description and Management

The WFD site was in the west-central portion of the WHC Sub-watershed (Figure 4.3). A 2-ha acreage was in the northwest corner of the quarter section, so the size of the field was 63 ha, of which an estimated 45 ha drained via a shallow channel to the northeast corner of the quarter section (Figure 4.39). The channel was often cultivated and cropped in drier springs; though, crop growth could be poor in the channel, depending on weather conditions.

The WFD site was within the CYLP1/U1h soil landscape model, as described by Agricultural Region of Alberta Soil Inventory (AGRASID) (Alberta Soil Information Centre 2013). Soils within this model include co-dominant (30 to 60%) Cygnet (Eluviated Black Chernozem) and Lonepine (Orthic Black Chernozem) soil series, with well drained characteristics. The landform in the model is described as undulating, with high relief and a limiting slope of 4%, and parent material consists of medium textured till and medium textured material over medium or fine textured till. The surface soil at the site had a loam texture (32% sand, 23% clay), a pH of 6.8, electrical conductivity of 0.7 dS m^{-1}, 4180 mg kg^{-1} TN, 743 mg kg^{-1} TP, and 9.1% organic matter (Appendix 4).

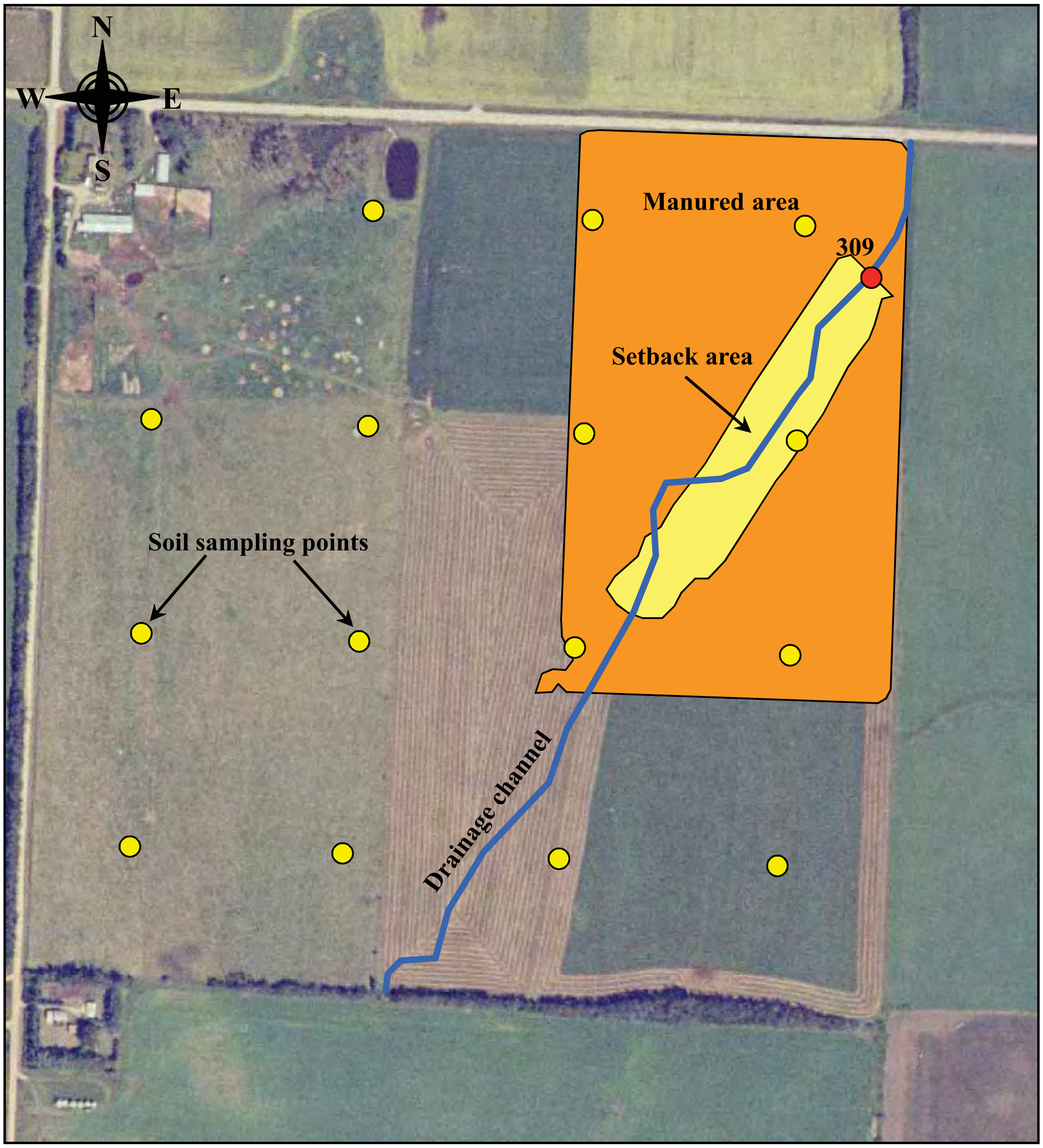

Figure 4.39. West Field site showing the drainage channel, water monitoring station (Station 309), soil sampling points, and the manured area in spring 2010 with a 30-m set back used in 2010.

Prior to this study, from 2000 to 2005, the WFD site was used as a pasture, except for the northeast corner, where about 20 ha were used for cereal crop production. Since then, the entire area has been used for annual crop production, with rotations including canola, barley, and wheat (Table 4.20). In 2008, only 39 ha were seeded as the southwest part of the field was too wet to seed. In preparation for fertilizing and seeding in the spring, the field was typically disc-tilled.

Table 4.20. Seeding and manure details at the West Field site from 2007 to 2012. [z]

				Commercial fertilizer					Tillage	
		Seeding	Manure	N	P	K	S	Cu	Discing	Harrowing
Year	Crop	date	date	------------- (kg ha^{-1}) -------------					date	date
				Pre-BMP						
2007[y,x]	canola	May 20	Oct 20[w]	na[v]	na	na	na	na	May 15-16[u]	May 21
	barley			-	-	-	-	-		
2008[t]	barley	May 17	-	140	70	47	-	-	May 10	-
2009[s,r]	canola	May 18	-	na	na	na	na	na	-	May 19[q]
				Post-BMP						
2010[p]	wheat	May 13	Apr 15-16[o]	193	61	32	22	3	May 13	-
2011[n]	wheat	May 30	-	59	15	26	3	9	May 30	-
2012[n]	canola	May 21	-	59	15	26	3	9	-	May 19

[z] Not all dates are exact.
[y] Canola on 32 ha on west side of field. Barley on 31 ha on east side.
[x] Application rate of 6.7 kg ha^{-1} of seed and unknown blend of fertilizer.
[w] Application of liquid hog manure at rate of 62 to 64 Mg ha^{-1} and incorporated by disc tillage on October 21.
[v] na = not available.
[u] Followed by two passes of harrows.
[t] 233 kg ha^{-1} of 60-30-20 on 39 ha.
[s] Dow Agroscience plots in southeast corner reduced total area to 61 ha.
[r] Unknown rate of 36-0-0-8 applied with seed.
[q] Followed by rollers on May 21.
[p] 265 kg ha^{-1} of 73-23-12-8.4-1 on the non-manured portion of the field, and liquid fertilizer of unknown composition on 30 ha along southern part of the field at a rate of 4.9 L ha^{-1} on June 17.
[o] Application of solid poultry manure at rate of 7.1 Mg ha^{-1} and incorporated with discs about April 22.
[n] 219 kg ha^{-1} of 27-7-12-1.2-4.

Inorganic fertilizer was applied just prior to or during seeding, and both were applied with a disc air drill at a depth of 3 to 5 cm, in the case of cereal crops. For canola seeding in 2007 and 2009, seeds were broadcasted on the surface, and rollers and harrows were used to cover the seed. Seeding dates varied from May 13 in 2010 to May 21 in 2012. Herbicide application at the WFD site occurred in mid-June, while fungicide was applied in mid-July when canola was grown (Table 4.21). The crop was either desiccated with an herbicide or swathed 3 to 4 wk prior to harvest. Harvest dates ranged from September 24 in 2012 to October 26 in 2009, with yields ranging from 1.35 to 4.95 Mg ha^{-1}. Straw was baled and removed only for canola crops and for wheat in 2010. After harvest, the field was typically tilled with disc and harrows, except in 2009 (Table 4.21).

In addition to inorganic fertilizer, the WFD site received manure applications every few years. Annual solid manure was applied to the 20-ha area from 2000 to 2005 and the entire field received liquid hog manure in 2006 and 2007. In 2007, the year preceding this study, liquid hog manure was surface applied at 62 to 64 Mg ha^{-1} to the entire field, and incorporated by disc tillage in fall 2007 (Table 4.20). Manure was not applied in 2008 and 2009.

In 2008, the farm operation was converted from hog to chicken broiler production. The conversion started with one barn containing 13,000 chickens in 2009. The operation expanded to 35,000 birds in two barns in 2010, with 6.5 production cycles per year.

4.6.2.2 Implementation of Beneficial Management Practices

The BMPs for the WFD site were implemented in the spring 2010 with the application of poultry manure. The BMPs involved changing the method, location, and timing of poultry manure application, compared to previous applications of hog manure, and using a nutrient management plan to determine the optimum manure and fertilizer application rates.

Changes in manure application included a setback distance of 30 m from the drainage channel as outlined by Agricultural Operation Practices Act (AOPA) (Province of Alberta 2010) for surface-applied manure. This distance was used as a result of the change to surface-spread solid poultry manure (2010) from injected liquid hog manure (2006 and 2007). Because of the recent conversion from hog to poultry production, there was not enough manure to apply to the whole field in 2010. Instead, an application area of 13.7 ha near Station 309 in the northeast corner was selected in order to capture the effects of the BMPs in the runoff (Figure 4.39). Finally, manure was applied in the spring after snowmelt instead of in the fall.

A nutrient management plan was used to determine the application rate of the manure. The plan was based on 2009 soil-test samples (Sub-section 4.6.3.2), manure nutrient content (Sub-section 4.6.3.3), the crop (wheat) grown in 2010 (Table 4.21), and the typical amount of P removed by the crop (Canadian Fertilizer Institute 2001). The use of the Alberta Farm Fertilizer Information and

Table 4.21. Pesticide and harvest management data at the West Field site from 2007 to 2012. [z]

		Pesticide		Pre-harvest		Harvest			
Year	Crop	Type[y]	Date	Method[x]	Date	Date	Yield ($Mg\ ha^{-1}$)	Straw	Disc date
					Pre-BMP				
2007	canola	H	Jun 15	S	Sep 15	Oct 15	1.96	yes	Oct 21
	barley	H	Jun 15	-	-	Oct 10	1.35	no	
2008	barley	H	Jun 18	D	Sep 10	Oct 7	4.95	no	Oct 14
2009[w]	canola	H	Jun 15	S	Sep 5	Sep 24	2.61	yes	-
		F	Jul 15						
					Post-BMP				
2010	wheat	H	Jun 17	D	Sep 6	Oct 8	4.16	yes	Oct 15[v]
2011	wheat	H	Jun 30	D	Sep 12	Oct 1	3.10	no	Oct 11-13[v]
2012	canola	H	Jun 15	S	Sep 5	Sep 24	1.54	yes	Oct 11-13[v]
		F	Jul 15						

[z] Not all dates are exact.
[y] H = herbicide, F = fungicide.
[x] S = swath, D = desiccant.
[w] Small area in northwest corner was swathed on September 5 and harvested on October 26 with similar yields.
[v] Followed by one pass of harrows.

Recommendation Manager (AFFIRM) software (AAFRD 2005b) determined that nutrient requirements for the 2010 crop year was 134 kg ha^{-1} N and no P, based on medium soil moisture conditions. An application rate of 7.1 Mg ha^{-1} (wet-weight basis) was determined to provide about 4 yr of harvested crop P removal, based on the manure nutrient analysis and the typical amount of P removed by wheat according to the Canadian Fertilizer Institute (2001). Solid poultry manure was applied at this site on April 15 and 16, 2010 using a vertical beater manure spreader (Figure 4.40). The surface applied manure was incorporated by tillage one week later.

The portion of the field that did not receive manure in spring 2010 received 265 kg ha^{-1} commercial inorganic fertilizer (73-23-12-8.4-CU1) on May 11. Manure was not applied to this field in 2011 or 2012 and commercial inorganic fertilizer was applied during these two crop years (Table 4.20). The AFFIRM program was used to determine fertilizer nutrient requirements for the 2011 wheat crop at 56 kg ha^{-1} of N and 5 kg ha^{-1} of P. The P recommendation was only for the area of the field that did not receive manure in 2010. No P fertilizer was recommended for the manured area. Actual amounts applied in 2011 were 59 kg ha^{-1} of N and 15 kg ha^{-1} of P. Three times the recommended P rate was applied in 2011, plus the P fertilizer was applied to the area that received manure in 2010. A nutrient management plan was not developed for the 2012 crop year, and the producer applied the same inorganic fertilizer at the same rate in 2012 as was used in 2011 (Table 4.20). In 2012, inorganic P fertilizer was also applied to the area that received manure in 2010.

4.6.2.3 Soil Sampling

Soil characterization samples (Sub-section 2.9) were collected on October 9, 2009. Soil agronomic samples (0- to 15-cm) were collected annually from 2007 to 2012 from a total of 15 sample points using a 200-m grid (Sub-section 2.9; Figure 4.39). The samples were collected in the

Figure 4.40. Manure application using a solid manure spreader with vertical beaters (Bunning Lowlander Widebody 230) at the West Field on April 15, 2010.

spring after seeding and the application of inorganic fertilizer or manure, and again in the fall after all field activities were completed. In 2011, an extra set of agronomic soil samples were collected prior to seeding so that pre- and post-seeding values could be compared (Sub-section 2.9.2).

Soil-test samples (0 to 60 cm) were taken from 2009 to 2011, generally using transects based on field topography (Sub-section 2.9). However, in 2010, because of time constraints, soil-test samples were collected in conjunction with the agronomic samples using the 200-m grid. It was assumed that due to the relatively low topographic relief of the field, the grid method captured variations within the field and provided representative samples comparable to the transect method.

4.6.2.4 Manure Sampling

Liquid hog manure was sampled in 2007 by collecting three, 1-L sub-samples from a single 10-L sample collected while the manure spreader was filled with manure from the storage lagoon.

Solid poultry (chicken broiler) manure was sampled in February 2010 by collecting six samples from two stockpiles of poultry manure (i.e., three samples from each stockpile). Each sample was a composite of four to five sub-samples. The same stockpiles were re-sampled using the same method in April 2010, just prior to field application. The results from the February samples were used to prepare a nutrient management plan, and the results from the April samples were used to confirm nutrient application rates. Samples were analyzed for water and nutrient content (Sub-section 2.10).

4.6.2.5 Water Flow and Quality Sampling

The WFD site was equipped with one edge-of-field monitoring station (Station 309), which included a circular flume and an automatic Isco water sampler (Sub-sections 2.6, 2.7, and 2.8). A total of 43 rainfall runoff (two pre-BMP and 41 post-BMP) and 32 snowmelt (13 pre-BMP and 19 post-BMP) samples were collected at this site during the study. The pre-BMP samples were taken from 2008 to snowmelt in 2010 and the post-BMP samples were taken from June 2010 to 2012.

Statistical analyses and load calculations are described in Sub-section 2.8.4. There were not enough pre-BMP rainfall runoff samples to perform pre-BMP versus post-BMP statistical tests, so only the snowmelt samples and all events combined were evaluated.

4.6.3 Results and Discussion

4.6.3.1 Implementation of Beneficial Management Practices

The application of poultry manure in spring 2010, as part of the BMP plan, was applied at the rate (7.1 Mg ha^{-1}) determined using the nutrient management plan. The implementation of the manure setback of no manure application within 30 m on each side of the drainage channel was generally followed, except that a 50-m section of the channel was mistakenly applied with manure (Figure 4.39). The drainage channel in this field was quite shallow and its course was difficult to see in places.

The nutrient management plan determined that no application of P was required for the 2010 crop year. Therefore, any application of manure would result in the application of excess P in terms of crop needs. The BMP plan was based on the application of poultry manure once every 4 yr, with a single application of manure that provided enough P equivalent to 4 yr of crop P removal. The manure application rate of 7.1 Mg ha^{-1} in spring 2010 was based on manure analysis of samples collected in February 2010. However, the analysis of additional manure samples taken at the time of application in April 2010 showed that the manure contained about 40% less water compared to the February samples. This meant the nutrients were more concentrated in the manure on a wet-weight basis because of the loss of water. As a result, the application rate used provided about 5 yr of crop P removal instead of the planned 4 yr of P removal.

Incorporation of the manure was delayed 1 wk, and this likely resulted in loss of ammonia (NH_3) through volatilization more than what was assumed in determining the manure application rate. It was assumed that about 25% of the NH_3 would be lost following application and prior to incorporation within 1 or 2 d. However, a longer delay for incorporation would have caused larger gaseous losses of N. The incorporation of surface-applied manure immediately after surface application improves the retention of manure N in the soil (McGinn and Sommer 2007).

As indicated above, the BMP plan was designed so that manure was applied in the spring once every 4 yr at a rate to meet crop P removal for a 4-yr period. Therefore, the application of fertilizer P would not be required in the 3 yr following the manure application year. After manure was applied at this site in spring 2010, no P application was required in 2011 and 2012. The concept is that by applying an excess amount of P in one year, the excess P will be removed by crop removal in the subsequent years prior to the next manure application. However, 15 kg ha^{-1} P inorganic fertilizer was applied in 2011 and 2012 (Table 4.20). Based on the crop yield in 2011 and 2012 (Table 4.21) and the typical amount of P removed by crops (Canadian Fertilizer Institute 2001), the estimated amount of P removed by the crop was 10 kg ha^{-1} in 2011 and 7 kg ha^{-1} in 2012. These estimated amounts of P removal were less than the amounts of inorganic P fertilizer applied, and as a result, it is unlikely the excess P applied from manure in 2010 was not reduced in the soil.

The cost of the BMPs was relatively small and only included the analysis of manure samples in early 2010, and soil sample analysis each fall from 2009 to 2011 (Table 4.22). The majority of labour was for soil sampling. The distance from the poultry manure storage area to the WFD site was about 3.2 km. Since the WSD site was a typical field the producer used for manure application, the cost of hauling manure was not part of the BMP costs.

4.6.3.2 Soil

Agronomic samples. Extractable NO_3-N concentration fluctuated during the project, but was consistently higher in the spring compared to the fall (Table 4.23). The concentration of NO_3-N in spring 2008 was 1.8- to 2.7-fold higher compared to the spring values in the other years. The higher concentration in spring 2008 was likely caused by the liquid hog manure applied in fall 2007.

Extractable NH_4-N and STP concentrations had no consistent seasonal patterns. The relatively high concentration of NH_4-N (19 mg kg^{-1}) measured in fall 2007 was likely caused by the liquid hog manure applied 13 d prior to soil sampling in fall 2007. By spring 2008, the NH_4-N concentration had decreased to 5 mg kg^{-1}. Ammonium typically converts quickly to NO_3, and this process of nitrification may have caused the higher NO_3-N concentration in spring 2008. The reason for a similarly high NH_4-N concentration in spring 2009 is unknown as no manure was applied in either 2008 or 2009. The highest concentrations of STP were in the spring and fall of 2008 (Table 4.23). Similar to NO_3-N and NH_4-N, the higher concentrations of STP were likely caused by the liquid hog manure application in fall 2007. Soil-test P concentration decreased after 2008 and then remained fairly steady and less than the agronomic threshold of 60 mg kg^{-1} (Howard 2006).

Soil-test samples. The concentrations of NO_3-N, NH_4-N, and STP decreased with soil depth in all 3 yr (Table 4.24). For the most part, nutrient concentrations were similar among the years. However, STP concentration appeared to decrease slightly with time, particularly in the fall. The concentrations of NO_3-N and NH_4-N in the top soil layer were similar to the agronomic soil sample values (Table 4.23); whereas, the STP concentrations were consistently less than for the agronomic soil samples.

Table 4.22. Cost of beneficial management practices at the West Field site.

Item	Cost ($)	Labour (h)
Soil sampling[z]	312.75	12
Manure sampling[y]	517.50	2
Nutrient management plan	-	3
Total	**830.25**	**17**

[z] Three samples (0-15, 15-30, 30-60 cm) were submitted each fall from 2009 to 2011, and the cost of analysis was $34.25 per sample.
[y] Six samples were submitted in February 2010, and the cost of analysis was $86.25 per sample. Additional samples were analyzed in April 2010 but were not included in the cost.

Table 4.23. Average concentrations for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for the agronomic soil samples collected from 2007 to 2012 at the West Field site.

	NO_3-N		NH_4-N		STP	
	Spring	Fall	Spring	Fall	Spring	Fall
Year	(mg kg^{-1})					
2007	-	25	-	19	-	52
2008	62	17	5	7	60	68
2009	23	5	18	6	49	46
2010	29	16	7	7	42	40
2011	34	12	6	5	56	42
2012	26	-	9	-	46	-

Table 4.24. Soil-test sample results for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for samples collected at the West Field site in the fall of 2009, 2010, and 2011.

Soil layer (cm)	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	STP (mg kg^{-1})
	2009		
0 to 15	7	6	37
15 to 30	3	5	21
30 to 60	1	4	10
	2010		
0 to 15	11	7	31
15 to 30	4	3	7
30 to 60	4	3	4
	2011		
0 to 15	5	4	30
15 to 30	2	3	6
30 to 60	1	2	3

Pre- and post-seeding samples. Though there were no significant differences between the pre- and post-seeding soil samples, the average concentrations of extractable NO_3-N, NH_4-N, and STP tended to be higher in the post-seeding samples compared to the pre-seeded samples (Table 4.25). In 2011, commercial inorganic fertilizer was applied prior to seeding (Table 4.20). The pre-seeding soil samples were collected about 1 wk before fertilizer application and the post-seeding samples were collected about 3 wk after fertilizer application. Even though the pre- and post-seeding values were not statistically different, the apparent increases after fertilizer application can be accounted for by the amount of N and P that were applied in 2011 (Table 4.20) by assuming a uniform distribution of applied fertilizer N and P in the top 15-cm of soil and a soil bulk density of 1200 kg m^{-3}.

Table 4.25. Average concentration of nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_3-N), and soil-test phosphorus (STP) in the 0- to 15-cm soil layer pre- and post-seeding at the West Field in spring 2011.

	NO_3-N	NH_4-N	STP
	------------------------------	(mg kg^{-1})	------------------------------
Pre-seeding[z]	10*a*[y]	4*a*	49*a*
Post-seeding[x]	34*a*	6*a*	56*a*

[z] Pre-seeding samples collected May 5, 2011.
[y] Averages for each parameter followed by the same letter are not significantly different ($P < 0.1$).
[x] Post-seeding samples collected June 2, 2011.

4.6.3.3 Manure

The liquid hog manure applied in 2007 contained very little solid matter, having 99% water content (Table 4.26). Ammonium N, total potassium (TK), and TN concentrations were similar to values reported by Olson and Papworth (2006) for southern Alberta. Total N concentration was less than the values reported by Olson and Papworth (2006), but within the concentration range in the Manure Characteristics and Land Base Code (AFRD 2006) used for AOPA (Province of Alberta 2010). Total P concentration was about one-third of the values reported by Olson and Papworth (2006) and AFRD (2000), and total sulphur (TS) concentration was six to seven times less (Table 4.24). The application rate of liquid hog manure (63 Mg ha^{-1}) provided 156 kg ha^{-1} TN and 19 kg ha^{-1} TP to the field in 2007. In 2008, the seeded wheat crop yield of 5 Mg ha^{-1} should have removed about 86 kg ha^{-1} TN and 18 kg ha^{-1} TP (Canadian Fertilizer Institute 2001). Thus, this rate of manure application was not excessive, considering that only a portion of the TN and TP in the hog manure would have become available for crop use within the year after application.

The water content in the stockpiled poultry manure decreased from 48% in February to 28% in April (Table 4.26), and the nutrient concentrations were generally higher in April. Therefore, the apparent increase in nutrient concentration was likely due to water loss. When expressed on a dry-weight basis (data not shown), the concentrations of NH_4-N, TP, TK, and TS were similar between the two sampling dates. The exception was for TN, which decreased in concentration from February to April. On a dry-weight basis, TN concentration was 86 kg Mg^{-1} in February and 51 kg Mg^{-1} in April. Since NH_4-N content remained the same on a dry-weight basis, N loss due to

Table 4.26. Average water and nutrient content in hog and poultry manure applied to the West Field site

Manure type	Sampling date	Water (%)[z]	NH_4-N	Total N	Total P	Total K	Total S	Total Na
			------------------------------		(kg Mg^{-1})[z]			------------------------------
Hog[y]	Oct 25, 2007	99	2.23	2.47	0.30	1.30	0.07	0.40
Poultry[x]	Feb 18, 2010	48	6.53	41.7	9.63	9.60	3.13	na[w]
Poultry[x]	Apr 14, 2010	28	9.11	37.1	12.8	13.7	4.79	na

[z] Values expressed on a wet-weight basis.
[y] n = 3.
[x] n = 6.
[w] na = not analyzed.

volatilization was likely minimal. Therefore, the reason for the decrease in TN concentration during the 2-mo period is unknown. The application rate of poultry manure (7.1 Mg ha^{-1}) provided 263 kg ha^{-1} TN and 91 kg ha^{-1} TP to the field in spring 2010. These amounts were 1.7-fold and 4.8-fold greater, respectively, than what was applied in the hog manure in 2007. The differences were caused by the higher concentrations of TN and TP in poultry manure compared to hog manure, even though the former was applied at a lower rate.

4.6.3.4 Water Flow and Quality

Water flow. Flow at the edge-of-field was generated mainly by rainfall events for most years, expcet for 2009 during which all of the annual flow was caused by snowmelt (Table 4.27). On average during the study period, 66% of the runoff from this site was caused by rainfall. The least amount of annual flow was in 2008 and the largest annual flow was in 2011. In 2008, nearly all the runoff occurred within 1 d (May 8) and was caused by rainfall (Figure 4.41). During the study, the least amount of precipitation occurred 2008, which received 35% less total precipitation than the 30-yr average (Sub-section 4.2). Precipitation from January to March in 2008 was 52% less than the 30-yr average and this resulted in no snowmelt-derived runoff in 2008. Precipitation from January to March in 2009 was 27% less than the 30-yr average, and all of the runoff in 2009 was caused by snowmelt. Total precipitation in 2009 was also well less than the 30-yr, but the total annual flow in 2009 was 76-fold greater than in 2008. The annual flow in 2010 was similar to 2009, but the total precipitation in 2010 was nearly 20% greater than the 30-yr average. Very little snowmelt runoff occurred in 2010 because the precipitation from January to March was 80% less than the 30-yr average. The drier than average conditions in 2008, 2009, and early 2010, may have favoured infiltration rather than runoff when the above-average precipitation occurred later (April to July) in 2010. The annual flow in 2011 was 12- to 24-fold larger than the annual flows in 2009, 2010, and 2012. The maximum peak flow measured (0.16 m^3 s^{-1}) occurred during snowmelt in 2011 (Figure 4.42a); however, 73% of the 2011 annual flow was caused by rainfall (Table 4.27; Figure 4.42b). The precipitation from January to March in 2011 was nearly twice the 30-yr average. The greater than average rainfall in 2010 and snowfall in early 2011 may have caused higher antecedent soil moisture and wetter spring conditions, which in turned caused more runoff during snowmelt and rainfall in 2011.

Table 4.27. Annual flow and percent of flow attributed to snowmelt and rainfall events at the West Field site from 2008 to 2012.

Year	Annual flow (m^3 yr^{-1})	Proportion from snowmelt (%)	Proportion from rainfall (%)
2008	58	0	100
2009	4,387	100	0
2010	4,265	4	96
2011	100,423	27	73
2012	8,341	40	60

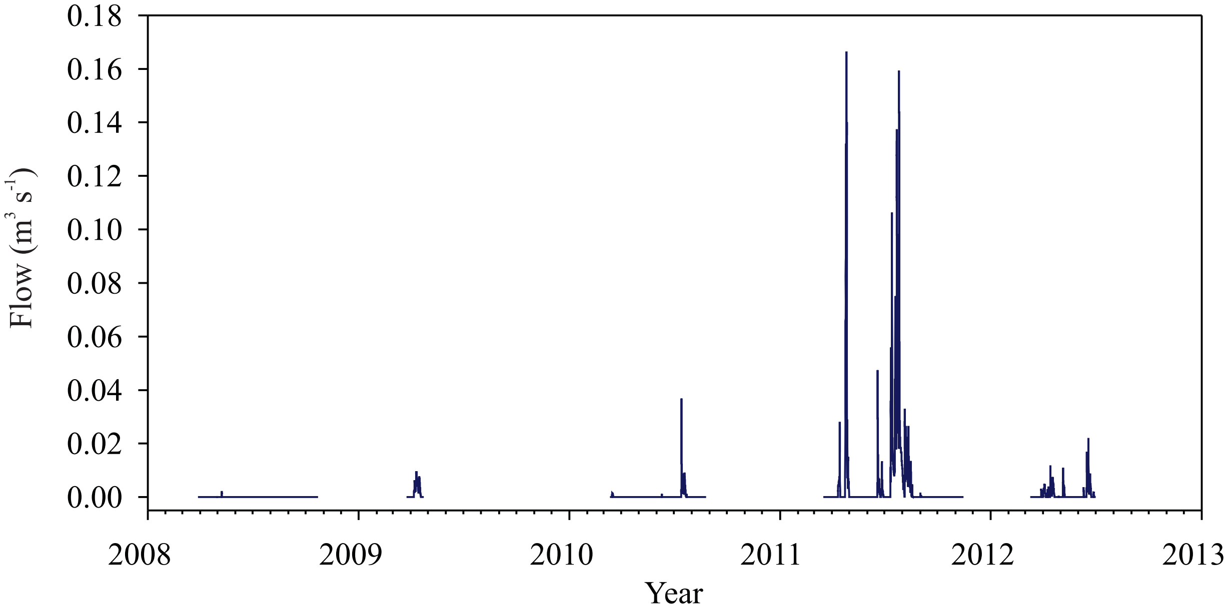

Figure 4.41. Hydrograph for Station 309 (edge-of-field) at the West Field from 2008 to 2012.

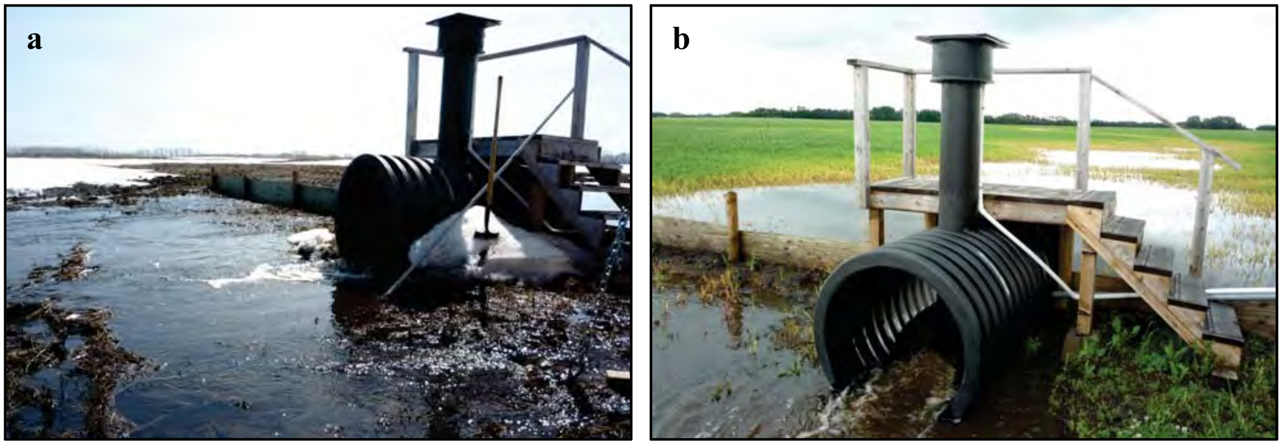

Figure 4.42. Runoff through the circular flume at Station 309 (a) from snowmelt on April 25, 2011 and (b) from rainfall on July, 26 2011 at the West Field.

General water quality observations. The 5-yr average concentrations of most parameters (TN, ON, NO_3-N, NH_3-N, PP, TSS, *E. coli*, and EC) were higher in rainfall runoff compared to snowmelt runoff (Table 4.28). The higher concentrations in rainfall runoff ranged from 1.4-fold (PP and EC) to 23-fold (*E. coli*) greater than in snowmelt runoff. In contrast, the 5-yr average concentrations of TP, TDP, and Cl were higher during snowmelt; whereas, average water pH was similar between the two event types.

Table 4.28. Average concentration of runoff water quality parameters measured at Station 309 at the West Field site from 2008 to 2012.[z]

Year	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli* (mpn 100 mL^{-1})	EC ($\mu S\ cm^{-1}$)	pH
		(mg L^{-1})											
Snowmelt[y]													
2009	11	5.35	3.30	1.95	0.03	1.28	1.23	0.06	10	33.6	6	374	7.80
2010	2	3.16	2.56	0.55	0.03	1.94	1.70	0.24	20	18.9	205	398	7.52
2011	9	6.95	1.86	4.97	0.08	0.64	0.60	0.04	7	9.15	1	204	7.56
2012	10	10.5	3.15	7.27	0.10	0.42	0.27	0.15	35	28.2	3	485	7.80
All	32	7.28	2.80	4.38	0.07	0.87	0.78	0.09	17	24.1	17	362	7.71
Rainfall[x]													
2008	2	76.0	2.55	73.1	0.37	1.61	1.42	0.20	43	n/a[w]	660	1054	7.35
2010	11	2.39	2.14	0.11	0.11	1.10	1.02	0.09	15	2.44	416	271	7.93
2011	22	9.07	3.36	5.59	0.07	0.74	0.61	0.13	22	17.4	399	420	8.12
2012	9	52.7	8.89	43.6	0.18	0.28	0.14	0.14	59	44.3	210	928	8.03
All	44	19.8	4.18	15.4	0.12	0.77	0.65	0.13	29	19.3	389	519	8.02

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] No snowmelt samples were collected in 2008.
[x] No rainfall samples were collected in 2009.
[w] This water quality parameter was added in late July 2008.

Total N concentration ranged from 1.98 to 152 mg L^{-1} at this site during the 5-yr period (Figure 4.43a). The highest concentrations were measured in 2008 and 2012. On average, 61% of TN in snowmelt runoff and 78% of TN in rainfall runoff was in the form of dissolved inorganic N (NO_3-N plus NH_3-N) (Table 4.28). However, the proportion of TN as dissolved N varied from year to year and ranged from 9% in 2010 (rainfall runoff) to 97% in 2008 (rainfall runoff).

The concentration of TP ranged from 0.15 to 2.09 mg L^{-1} (Figure 4.43b) and varied less than TN. The annual average TP concentration decreased with time from 1.61 mg L^{-1} in 2008 to 0.36 mg L^{-1} in 2012. The decrease in TP annual average concentration was primarily due to a decrease in TDP concentration. The concentration of PP did not show a similar trend and was more consistent with time. On average, 90% of TP in snowmelt runoff and 84% of TP in rainfall runoff was in the form of TDP (Table 4.28). The relatively high proportion (>82%) of TP in dissolved form was consistent from 2008 to 2011. In 2012, the TDP portion of TP was only 64% in snowmelt runoff and 50% in rainfall runoff.

The concentration of TSS was generally consistent from 2008 to 2011 (Table 4.28; Figure 4.43c). However, in 2012, there were several higher peak concentrations (124 to 288 mg L^{-1}) compared to the previous years.

The concentration of *E. coli* ranged from 0.5 to 3076 mpn 100 mL^{-1} from 2008 to 2012 (Figure 4.43d). The highest peak concentrations were observed in 2010 and 2011. The highest average concentration (660 mpn 100 mL^{-1}) of *E. coli* was in 2008 (Table 4.28). The higher average concentrations of *E. coli* in rainfall runoff compared to snowmelt runoff, as indicated above, was probably caused by warmer temperature during the former event type yielding more microbial activity in the soil.

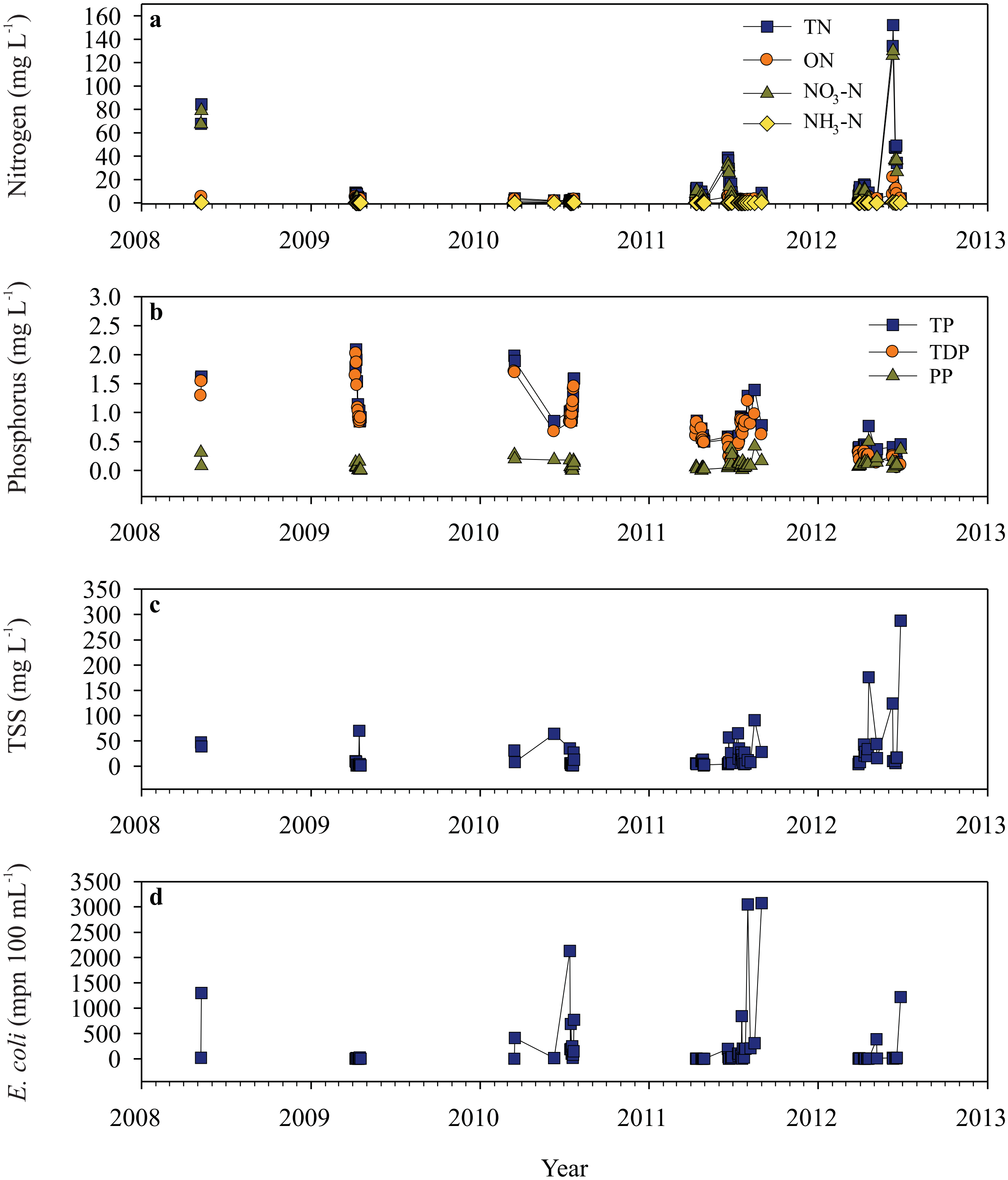

Figure 4.43. Concentrations of (a) total nitrogen (TN), organic nitrogen (ON), nitrate nitrogen (NO_3-N), and ammonia nitrogen (NH_3-N); (b) total phosphorus (TP), total dissolved phosphorus (TDP), and particulate phosphorus (PP); (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) measured at the edge-of-field monitoring Station 309 at the West Field from 2008 to 2012.

Annual nutrient and TSS loads exported were primarily influenced by annual flow. The largest loads occurred in 2011, which was the year with the largest annual flow (Table 4.29). Similarly, the smallest loads for most parameters occurred in 2008, which was the year with the smallest annual flow. The loads in 2011 ranged from 55-fold (NO_3-N) to 957-fold (PP) larger than in 2008. Because parameter concentrations were generally less in 2011, the magnitude of the higher loads in 2011 was less than the magnitude difference between annual flows, which was more than 1700-fold greater in 2011 compared to 2008 (Table 4.27). For most parameters, the second highest loads were in 2012, which had the next highest annual flow in the 5-yr period (Table 4.27). Exceptions were for TP and TDP loads, which were higher in 2009 and 2010, even though these two years had less annual flows than in 2012. In 2009 and 2010, the annual flows were similar at more than 4000 m^3 yr^{-1}. However, loads varied between these two years depending on the parameter. The loads of TN, ON, NO_3-N, TP, and TDP were 1.2- to 11-fold higher in 2009 compared to 2010; whereas, the loads of NH_3-N, PP, and TSS were 40 to 60% less in 2009 compared to 2010. Perhaps some of these differences between the two years were due to the difference in the dominant runoff type. Most of the runoff in 2009 was caused by snowmelt and most of the runoff in 2010 was caused by rainfall (Table 4.27). For example, the smaller load of TSS (and PP) in 2009 may have been caused by less erosion of particulate material during the freeze-thaw conditions of snowmelt.

BMP effects on water quality. The average concentrations of ON, TP, and TDP in snowmelt runoff were significantly less in the post-BMP period compared to the pre-BMP period (Table 4.30). These results support the hypothesis that the BMPs (spring-applied manure, setbacks, and nutrient management plan) would improve water quality of runoff at this site. In contrast however, the concentrations of TN, NO_3-N, NH_3-N, TSS, and Cl were significantly higher in the post-BMP period and there were no significant differences between the pre- and post-BMP periods for PP, *E. coli*, EC, and pH. It was hypothesized that dissolved nutrients would respond positively to the implemented BMPs, and this was the case for P. However, dissolved forms of N (NO_3-N and NH_3-N) actually increased in the post-BMP snowmelt. The average value for PP was higher in the post-BMP period but was not significantly different from the pre-BMP period. A higher PP concentration in the post-BMP period would be expected since TSS concentration was significantly higher after the BMPs were implemented. Organic N is also associated with TSS, but instead of increasing in concentration from the pre- to post-BMP periods with TSS, the average ON concentration was significantly decreased.

Table 4.29. Annual loads of nutrients and total suspended solids in runoff at the West Field site from 2008 to 2012.

Year	TN [z]	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
	($kg\ yr^{-1}$)							
2008	4.75	0.25	4.47	0.01	0.09	0.09	0.01	2
2009	24.0	13.71	9.75	0.12	5.59	5.35	0.25	36
2010	9.53	8.23	0.86	0.33	4.55	4.11	0.44	74
2011	497	246	244	6.08	76.5	67.0	9.57	1695
2012	206	50.9	154	0.78	2.49	1.33	1.15	279

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids.

For all events combined, the average concentrations of TP, TDP, and Cl were significantly less in the post-BMP period compared to the pre-BMP period (Table 4.30). The average concentrations of NH_3-N, TSS, and pH were significantly higher in the post-BMP period compared to the pre-BMP period. And there were no significant differences between the two periods for the remaining parameters. It should be noted that for all events combined, the dataset is highly unbalanced, with four times more samples for the post-BMP period compared to the pre-BMP period, so caution should be taken when interpreting these data. Only two rainfall runoff samples were collected in the pre-BMP period compared to 42 samples in the post-BMP period.

To explain why some parameters were significantly increased, some were significantly decreased, and the remainder were not significantly different between the two BMP periods is difficult based on measured indicators. The average concentration of soil nutrients between the two BMP periods were similar (Table 4.23). Extractable NO_3-N was 26 and 23 mg kg^{-1}, NH_4-N was 11 and 9 mg kg^{-1}, and STP was 55 and 45 mg kg^{-1} between the pre-BMP and post-BMP periods, respectively. The soils data did not reflect a BMP effect that could explain either the decreases or increases in the concentration water-quality parameters. As previously described, the amount of manure nutrients applied in the post-BMP period was actually higher compared to the pre-BMP period (Sub-section 4.6.3.3). This could explain the significant increases in the concentrations of TN, NO_3-N, NH_3-N, and Cl in snowmelt runoff during the post-BMP period, but does not explain the decreases in the concentrations of ON, TP, and TDP. This contrast is particularly true for P, which was applied in the post-BMP period at nearly five times the amount that was applied in the pre-BMP period. Finally, precipitation in 2010 and 2011 and the annual flow in 2011 were larger compared to the other years. The losses of TN and dissolved inorganic N have been attributed to increased N leaching and export during wet conditions in other studies (Donner et al., 2004; Donner and Scavia 2007; Nangia et al, 2010). The high annual flow in 2011 did not have a consistent effect on concentration among the water quality parameters in the current study (Table 4.28).

Table 4.30. Average water quality parameter concentrations during the pre-BMP and post-BMP periods during snowmelt at the West Field site. [z]

BMP period	n	TN[y]	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli* (mpn 100 mL^{-1})	EC ($\mu S\ cm^{-1}$)	pH
		----------	----------	----------	----------	(mg L^{-1})	----------	----------	----------	----------			
						Snowmelt							
Pre	13	5.01*b*	3.18*a*	1.74*b*	0.03*b*	1.38*a*	1.30*a*	0.08	11*b*	13.0*b*	40	378	7.75
Post	19	8.83*a*	2.54*b*	6.18*a*	0.09*a*	0.53*b*	0.43*b*	0.10	22*a*	19.0*a*	2	352	7.68
						All events							
Pre	15	14.5	3.10	11.3	0.08*b*	1.41*a*	1.31*a*	0.10	15*b*	31.4*a*	128	468	7.70*b*
Post	61	14.2	3.70	10.4	0.10*a*	0.67*b*	0.56*b*	0.11	26*a*	19.2*b*	251	447	7.94*a*

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

[y] Averages for each parameter with letters are significant different ($P < 0.1$).

4.6.4 Conclusions

- Even though this site had a history of manure application, soil testing showed that the nutrient levels of N and P were not excessive. Soil-test P concentrations were generally less than the 60 mg kg^{-1} agronomic threshold, expect in 2008 caused by hog manure applied in fall 2007.
- Annual flow was quite variable at this site, ranging from nearly no flow (2008) to more than 100,000 m^3 yr^{-1} (2011).
- On average from 2008 to 2012, 66% of the runoff was caused by rainfall and the remainder caused by snowmelt. However, the proportion of runoff generated by rainfall varied from 0 to 100% among the years.
- The 5-yr average concentrations of TN, ON, NO_3-N, NH_3-N, PP, TSS, *E. coli*, and EC were 1.4- to 23-fold higher in rainfall runoff compared to snowmelt runoff. In contrast, the 5-yr average concentrations of TP, TDP, and Cl were higher during snowmelt.
- The concentration of TN ranged from 1.98 to 152 mg L^{-1} and the concentration of TP ranged from 0.15 to 2.09 mg L^{-1}. On average, 61% of TN in snowmelt runoff and 78% of TN in rainfall runoff was in the form of dissolved N (NO_3-N and NH_3-N), and 90% of TP in snowmelt runoff and 84% of TP in rainfall runoff was in the form of TDP.
- The cost of the BMPs at this site was relatively low at $830, which was for the analysis of soil and manure samples.
- The average concentrations of ON, TP, and TDP in snowmelt runoff were significantly less in the post-BMP period compared to the pre-BMP period. In contrast, the concentrations of TN, NO_3-N, NH_3-N, TSS, and Cl were significantly higher in the post-BMP period and there were no significant differences between the pre- and post-BMP periods for PP, *E. coli*, EC, and pH. Therefore, the effects the BMPs (spring application of manure, 30-m setback, and nutrient management plan) on water quality were inconclusive at this site.
- A positive BMP effect was marginal at this site, but may have reduced the loss of P in runoff. The increase in loss of N in runoff in the post-BMP period may have been caused by the wet conditions compared to the pre-BMP period. The application of poultry manure at three to four times the annual crop-P removal once every three to four years had little net benefit of improving edge-of-field water quality compared to previous manure application practices at this site.
- From a water quality perspective, it was inconclusive on whether or not to continue these BMPs at this site. The financial cost of the BMPs was relatively minimal.

4.7 North Field

4.7.1 Introduction and Hypotheses

The NFD site was a quarter section of cropland with a confined dairy operation, and the site was in the northwest portion of the WHC Sub-watershed. A tributary of WHC bisected the property. Manure was fall-applied annually from 2007 to 2012 to the cultivated areas of the site. While soil nutrient concentrations were slightly higher compared to the other BMP sites in the WHC Sub-watershed, the values were not considered too excessive.

The BMPs included the use of a nutrient management plan to optimize the use of nutrients. Additional BMPs included the use of liquid manure injection, application setbacks, relocation of manure storage, and erosion control to reduce nutrients, bacteria, and solids entering runoff and reaching the creek. The underlying assumption was that surface-application and incorporation of manure without setbacks, and without a nutrient management plan, would contribute dissolved nutrients to rainfall and snowmelt runoff at this site. The hypothesis was:

- The conversion from surface-applied to injected liquid manure, application of manure based on crop-P removal, use of setbacks, relocation of manure storage, and implementation of erosion control would reduce the concentration of water quality parameters in edge-of-field runoff and in the tributary.

4.7.2 Methods

4.7.2.1 Site Description and Management.

The NFD site was located in the northwest portion of the sub-watershed (Figure 4.3) and consisted of a confined dairy operation and cropland. The site was 61 ha in size, with a 3.4-ha farmyard and dairy facilities along the east side of the quarter section (Figure 4.44). A gradually sloped tributary channel of WHC flowed from north to south through the middle of the quarter section. The tributary drained a seasonal wetland north of the NFD site and was inhabited by typical hydrophytic plants, such as bulrushes (*Typha spp*.). This area was considered part of the upper headwaters in the sub-watershed. Local surface runoff flowed into the tributary through a few shallow field drainage channels, which were generally cultivated through. The drainage area to the west of the tributary extended into the adjacent field on the west side of the NFD site.

The southeast corner of the NFD quarter section was in the CYLP2/U1hc soil landscape model, as described by AGRASID (Alberta Soil Information Centre 2013). Soils within this model include co-dominant (30 to 60%) Cygnet (Eluviated Black Chernozem) and Lonepine (Orthic Black Chernozem) soil series and significant (10 to 30%) Miscellaneous Gleysol (Orthic Humic Gleysol) soil series, with poor and well drained characteristics. The landform in the model is described as undulating, with high relief and a limiting slope of 4%, and parent material consists of medium textured till, medium textured material over medium or fine textured till, and undifferentiated material. The remainder of the NFD quarter section was in the PED2/U1h AGRASID soil landform model. Soils in this model include dominant (>60%) Penhold (Orthic Black Chernozem) soil series and significant (10 to 30%) Cygnet (Eluviated Black Chernozem) and Miscellaneous Gleysol (Orthic Humic Gleysol) soil series, with poor and well drained characteristics. The landform in the model is described as undulating, with high relief and a limiting slope of 4%, and parent material consists of medium textured sediment deposited by wind and water, medium textured till, and undifferentiated material. The surface soil at the site had a loam texture (36% sand, 23% clay), a pH of 6.8, electrical conductivity of 1.1 dS m^{-1}, 4550 mg kg^{-1} TN, 717 mg kg^{-1} TP, and 9.7% organic matter (Appendix 4).

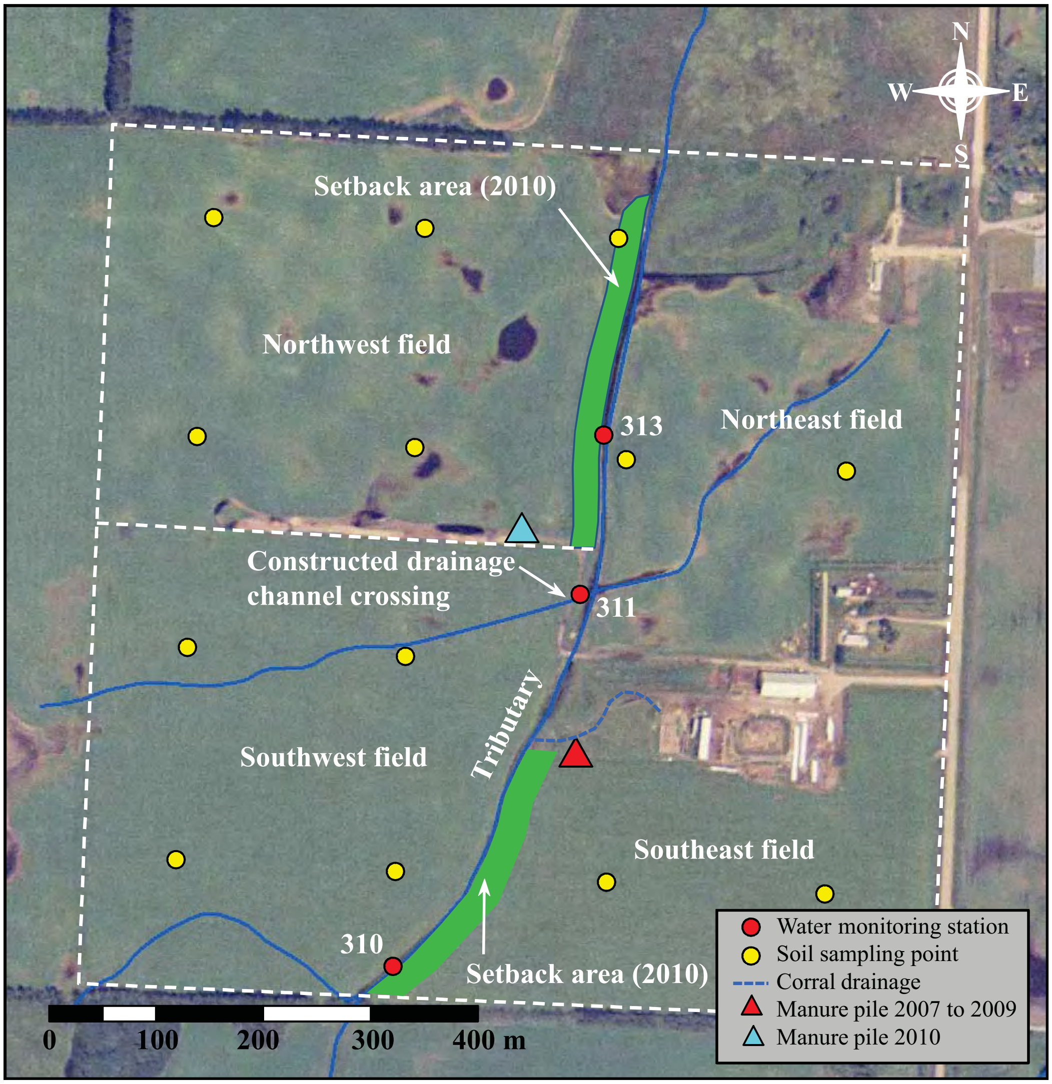

Figure 4.44. The North Field site showing the four fields, the three water monitoring stations (Stations 310, 311, and 313), agronomic soil sampling points, the manure application setbacks along the main drainage channel used in fall 2010, and the location of the old and relocated manure piles.

The NFD site consisted of a farmyard and four field management units: northwest (17 ha), northeast (11 ha), southeast (10.5 ha), and southwest (16 ha). Crops were primarily grown for forage, rotating between perennial alfalfa (*Medicago sativa*) and annual cereal crops. From 2007 to 2012, two of the four fields were used to produce alfalfa, except in 2009 when only the southwest field was in alfalfa (Tables 4.31 and 4.32). The alfalfa fields were harvested as silage crops two times per year in June or July and in August or September. The other fields were seeded in spring with a barley or corn for silage, and on occasion, a wheat crop for grain. The annually-cropped fields were typically tilled to a 7.5- to 10-cm depth with a cultivator prior to seeding, and heavy rollers were typically used after seeding. Fertilizer was applied with the barley seed in 2007 and with the corn crops in 2009 and 2010. Fertilizer was also applied to the alfalfa in the southwest field in the spring of 2009 and 2010 (Table 4.31).

Annually-cropped fields were often sprayed with a herbicide a few days before or after seeding (Tables 4.31 and 4.32). Spraying also occurred about a month after seeding, or in the fall after harvest (Table 4.31). Roundup® herbicide was the preferred herbicide, but Stellar® (2010) and Spectrum® herbicide (2012) were also used. Roundup herbicide was also sprayed to desiccate wheat before harvest in 2009 and 2010 and alfalfa in 2008 and 2011.

In 2007, livestock consisted of 55 milking cows, 10 dry cows, 45 heifers, 25 calves, and 18 cull cows. There was essentially no grazing at this site, except for a small, 1-ha area in the farmyard that was used by two to four horses from 2007 to 2012. The milking cows were kept in a loose housing barn with straw bedding, from which the majority of the solid manure was produced. Solid manure was stocked piled in the field prior to application. Additional solid manure was produced from the other types of dairy livestock. The milking parlour and holding area collected liquid manure, which was stored in an earthen lagoon. Solid and liquid dairy manure was fall-applied on an annual basis to the cultivated areas. Since the producer had limited field equipment, most field operations were completed by a custom agricultural operator. From 2007 to 2012, solid and liquid manure was applied after harvest to all annually cropped fields and to desiccated alfalfa fields (Table 4.33). The solid manure was surface applied and incorporated by cultivator or disc tillage, except in 2011 when the ground was too frozen. Prior to the pre-BMP period, liquid manure was surface applied and incorporated from 2007 to 2010. Liquid manure application rates varied from 90 to 135 Mg ha^{-1}, while solid manure rates varied from 19 to 52 Mg ha^{-1} (Table 4.33). Liquid hog manure was applied at an unknown rate to the adjacent quarter section directly west of NFD site on May 6, 2008.

Table 4.31. Management practices at the North Field during the pre-BMP monitoring period (2007 to 2010).[z]

						Fertilizer			Pesticide[x]	
			Seeding	Harvest	Yield[y]	N	P	K		Rate
Year	Field	Crop	date	date	(Mg ha^{-1})	---- (kg ha^{-1}) ----			Date	(L ha^{-1})
				Pre-BMP period						
2007	NW[w]	barley	Jun 1	Jul 27	20.2	22	17	11	Jun 4	1.9
									Sep 1	1.9
	NE[w,v]	barley	Jun 1	Jul 27	20.2	22	17	11	Jun 4	1.9
									Sep 1	1.9
	SE	alfalfa	-	Jun 27	17.9	-	-	-	-	-
				Aug 29	13.5					
	SW	alfalfa	-	Jun 27	17.9	-	-	-	-	-
				Aug 29	13.5					
2008	NW	corn	May 12-16	Oct 9	30.0	na[u]	na	na	na	na
	NE	barley	May 12-16	Aug 4	28.8	na	na	na	-	-
	SE	alfalfa	-	Jun 26	13.4	na	na	na	Aug 8[t]	na
				Aug 11	1.5[s]					-
	SW	alfalfa	-	Jun 26	13.4	na	na	na	na	na
				Aug 5	12.9					
				Oct 3	2.2[s]					
2009	NW[r,q]	corn	May 2	Oct 5	35.9	52	0	0	na	na
	NE	barley	May 8	Aug 10,17	25.6	na	na	na	-	-
	SE	wheat	May 6	Sep 14-18	4.0[p]	na	na	na	Sep 3[t]	na
	SW[o]	alfalfa	-	Jul 8	9.4	22	0	78		
				Sep 1	2.2[s]					
2010	NW	wheat	May 6	Oct 10	5.4[p,n]	-	-	-	Jun 5[m]	RAR
									Aug 30[t]	0.33
	NE	alfalfa	May 14	Aug 27	6.7	-	-	-	Jun 9[l]	RAR
	SE[q]	corn	May 3	Oct 12	22.4	52	0	0	Jun 18	1
	SW[k]	alfalfa	-	Jul 6	11.2	18	0	63		
				Aug 31	9.0					

[z] Not all dates are exact.
[y] Yields are for silage (wet weight) unless indicated otherwise.
[x] Pesticide is Roundup® herbicide unless noted otherwise. RAR = recommended application rate.
[w] 112 kg ha^{-1} of 20-15-10.
[v] 4 ha in NE corner not seeded because it was too wet.
[u] na = not available.
[t] Used to desiccate crop.
[s] Removed as hay bales.
[r] A 2-ha strip along the east side was seeded to barley and harvested on Aug 4.
[q] 112 kg ha^{-1} of 46-0-0.
[p] Harvested as grain.
[o] 280 kg ha^{-1} of 8-0-28-10-10 applied on April 21.
[n] Straw removed as 150 bales at 408 kg each on October 11.
[m] Stellar® herbicide.
[l] Cutworm insecticide.
[k] 224 kg ha^{-1} of 8-0-28-10-10 applied on May 15.

Table 4.32 . Management practices at the North Field during the post-BMP monitoring period (2011 to 2012) .[z]

						Fertilizer			Pesticide[x]	
			Seeding	Harvest	Yield[y]	N	P	K		Rate
Year	Field	Crop	date	date	(Mg ha^{-1})	---- (kg ha^{-1}) ----			Date	(L ha^{-1})
2011	NW[w]	barley	Jun 6	Sep 8	12.8	-	-	-	May 27	1.9
	NE	alfalfa	-	Jul 9	6.4	-	-	-	-	-
				Sep 8	6.4					
	SE	corn	May 13	Oct 17	30.3	-	-	-	Jun 3	1.9
									Jun 24	1.9
	SW	alfalfa	-	Jul 9	11.2	-	-	-	Sep 3[v]	3.7
				Sep 8	8.4					
2012	NW	alfalfa	-	Jul 5	20.5	-	-	-	-	-
				Sep 5	20.5					
	NE	alfalfa	-	Jul 5	10.4	-	-	-	Aug 23[v]	na
				Aug 5	5.1					
	SE	barley	May 14	Aug 7	26.9	-	-	-	Jun 5[u]	RAR
	SW[t]	corn	May 12	Oct 1	31.4	-	-	-	Jun 4	RAR
									Jul 4	RAR

[z] Not all dates are exact.
[y] Yields are for silage (wet weight) unless indicated otherwise.
[x] Pesticide is Roundup® herbicide unless noted otherwise. RAR = recommended application rate.
[v] Used to desiccate crop.
[w] Barley under seeded with alfalfa.
[u] Spectrum® herbicide.
[t] 5 ha on east side of field seeded to barley with same management details as barley in SE field.

4.7.2.2 Implementation of Beneficial Management Practices

The BMPs implemented at this site included the development of nutrient management plans to determine manure application rates, conversion from surface applied to injected liquid manure, use of manure setbacks from the tributary, relocation of a solid-manure stockpile site, and erosion control. The timing and location of some BMPs varied according to the crop rotation among the four fields (Table 4.34).

Nutrient management plans were developed for the 2011 and 2012 crop years based on analysis of nutrients in soil (Sub-section 4.7.2.3) and manure samples (Sub-section 4.7.2.4) and the type of crop grown (Table 4.31). Nutrient management plans were developed for two fields in each year: northwest and southeast fields in 2011 and southeast and southwest fields in 2012. Nutrient requirements were determined using the AFFIRM software (AAFRD 2005b).

Table 4.33. Manure application details at the North Field site from 2007 to 2012.[z]

					Tillage			
Year	Field	Date	Type	Rate (Mg ha^{-1})	Date	Type	Depth (cm)	Delay[y] (d)
				Pre-BMP period				
2007	NW	Aug 10	liquid	na[x]	Aug 22	cultivator	10-15	12
					Oct 1			-
	NE	Aug 20	solid	47	Aug 22	cultivator	10-15	2
					Oct 1			-
2008	NW	Oct 17	solid	19	Oct 27	cultivator	na	10
	NE	Aug 11	solid	52	Aug 19	cultivator	na	8
	SE	Aug 23	liquid	135	Aug 29	cultivator	na	6
		Aug 27	solid	38				2
2009	NW	Oct 9	liquid	90 [w]	Oct 24	cultivator	10	15
		Oct 16	solid	43				8
	NE	Oct 16	solid	24	Oct 24	cultivator	10	8
	SE	Oct 09	liquid	90	Oct 24	cultivator	10	15
		Oct 16	solid	35				8
2010	NW	Oct 22	liquid	90	Oct 25	disc	7.5-10	3
		Nov 1	solid	21.3	Nov 2	cultivator	7.5-10	1
	SE	Oct 22	liquid	90	Oct 25	disc	7.5-10	3
		Nov 1	solid	21.6	Nov 2	cultivator	7.5-10	1
				Post-BMP period				
2011	SE	Nov 11	solid	22.4	-	none	-	-
	SW	Sep 8	liquid[v]	108	Sep 21 (2x)[u]	disc	7.5-10	-
		Sep 16	Solid	22.4	Oct 28	cultivator	7.5-10	5
2012	NE	Aug 30	liquid[v]	90	Sep 4 (2x)	disc	7.5-10	-
	SE	Aug 24	Solid	22.4	Sep 4 (2x)	disc	7.5-10	11
		Aug 30	liquid[v]	90				-
	SW	Aug 24	solid	22.4[t]	Sep 4 (2x)	disc	7.5-10	11
		Oct 16	solid	22.4[s]	Oct 18	disc	7.5-10	2

[z] Not all dates are exact.
[y] The number of days that tillage was carried out after the surface application of manure. This was not relevant for injected liquid manure.
[x] na = not available.
[w] Only on 15 ha of corn.
[v] Liquid manure was injected. For all other times, liquid manure was surface applied and incorporated.
[u] 2x = two tillage passes.
[t] On 5.3 ha of barley.
[s] On 8.9 ha of corn.

Table 4.34. Implemented beneficial management practices in 2010 and 2011 at the North Field site.

	Fields in 2010				Fields in 2011			
BMP	NW	NE	SE	SW	NW	NE	SE	SW
Nutrient management plan[z]	x		x				x	x
Manure injection								x
Manure setbacks	x		x				x	x
Manure storage relocation			x				x	
Erosion control				x				x

[z] Final application rates were based on annual crop removal of total phosphorus.

Soil sampling was delayed in fall 2010 and soil-test results were not available at the time manure was applied. Therefore, soil-test results were used from fall 2009 as proxy values. Also, manure samples were only taken at the time of application in fall 2010. Average manure nutrient content values were based on the 2007 to 2009 samples for solid manure and the 2008 to 2009 samples for liquid manure. In fall 2010, the AFFIRM results showed that no P was required in both fields and no N was required in the southeast field for the 2011 crop year. A small amount of N was recommended for the northwest field, but it was assumed the required N would be supplied from the residual N from previous manure applications. However, the producer had a large supply of manure and required land to dispose of the manure. Even though no added nutrients were required on the fields, manure was applied based on 1 yr of total P removal by the crops. The calculated applications rates for manure were 92 and 74 Mg ha^{-1} of liquid manure for the southeast and northwest fields, respectively, and 13 Mg ha^{-1} of solid manure on the northwest field. The actual liquid manure application rate was very similar to the calculated value; whereas, a higher rate of solid manure was applied on the northwest field, and solid manure was also applied to the southeast field (Table 4.33). The intent was to change liquid manure application from surface applied to injected in fall 2010. However, the liquid manure contained too much straw for injection and the manure was surface applied and incorporated, which was the same as the application practice in the pre-BMP period.

In fall 2011, a nutrient management plan was developed for two fields: southeast and southwest fields. Fall 2011 soil sampling was delayed and soil-test results were not available at the time manure was applied. Therefore, soil-test results were used from fall 2010 as proxy values. Also, manure samples were only taken at the time of application in fall 2011. Average manure nutrient content values were based on 2007 to 2010 samples for solid manure and on 2008 to 2009 samples for liquid manure. Nutrient requirements were determined using the AFFIRM software (AAFRD 2005b). The crops grown in 2012 were barley silage on the southeast field and corn silage on the southwest field. Results from the AFFIRM program predicted 28 kg ha^{-1} N and no P for the southeast field and 134 kg ha^{-1} N and 12 kg ha^{-1} P for southwest field. It was anticipated that the small amount of N required for the southeast field would be supplied from residual N from the manure applied in fall 2010. Therefore, the application of nutrients was not required for the southeast field. However, as in fall 2010, stored manure was applied in 2011 based on 1 yr of TP removal by the crops. The calculated manure rates were 15.5 Mg ha^{-1} solid manure on the southeast field and 119 Mg ha^{-1} liquid manure on the southwest field. The actual application rates were slightly higher for the solid manure and slightly lower for the liquid manure (Table 4.33). Plus, solid manure was also applied to the southwest field. In 2011, the liquid manure was successfully applied by injection directly into the alfalfa stubble using a drag-hose system and disk openers (Figure 4.45). There was minimal disturbance to the soil surface and very little manure pooled on the soil surface (Figure 4.45).

As part of the BMP plan, setback areas along the tributary where manure was not applied were used in fall 2010, 2011, and 2012 (Figure 4.44). For surface applied manure (liquid and solid) a 30-m setback was used, and for injected liquid manure a 10-m setback was used, as outlined in AOPA (Province of Alberta 2010). As well, the producer initiated setbacks for manure application in fall 2009.

In 2010, a solid-manure storage site was relocated further away from the tributary and in a location less susceptible to runoff (Figures 4.44). The original storage site was near the tributary and next to a drainage channel from the farmyard corrals (Figures 4.44 and 4.46a).

The break-up of alfalfa in the southeast field in fall 2008 was identified as a potential source of increased nutrient and sediment loss in runoff water due to increased erosion risk. Therefore, when the alfalfa crop in the southwest field was terminated after the 2011 growing season, a 15-m semi-circle forage buffer area was left along part of the field drainage channel leading to Station 311. The buffer area did not receive manure and was not tilled in the fall. However, the buffer area was desiccated on September 3, 2011 when the whole field was sprayed, and the area did not rejuvenate very well. The buffer area was subsequently seeded to barley in spring 2012.

Figure 4.45. Tractor pulling a drag-hose system with disk openers used to inject manure in the southwest field at the North Field site on September 8, 2011.

Another area of concern for erosion was a crossing through the field drainage channel immediately upstream of Station 311 in the southwest field (Figure 4.47a). This crossing was used to access the northwest field with farm machinery. There were obvious signs of erosion, which was exacerbated during extended periods of runoff. The crossing was modified by installing a culvert (0.4 m in diameter and 7.62 m long) covered with 33 Mg of fill clay and 24 Mg of crushed 60-mm gravel (Figure 4.47b). The constructed crossing was complete on July 27, 2010.

4.7.2.3 Soil Sampling

Soil characterization samples (Sub-section 2.9) were collected on October 22, 2009. Soil samples collected annually at this site included 0- to 15-cm agronomic samples (2007 to 2012) and soil-test samples (2009 and 2010) (Sub-section 2.9).

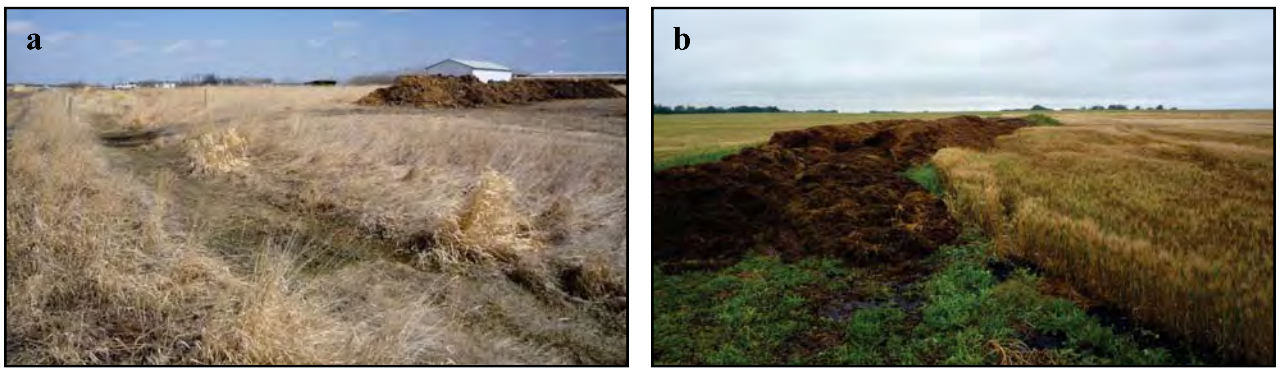

Figure 4.46. Solid manure storage area at the (a) original location in April 2008 and at the (b) new location in September 2010. Note the tributary channel in the left image.

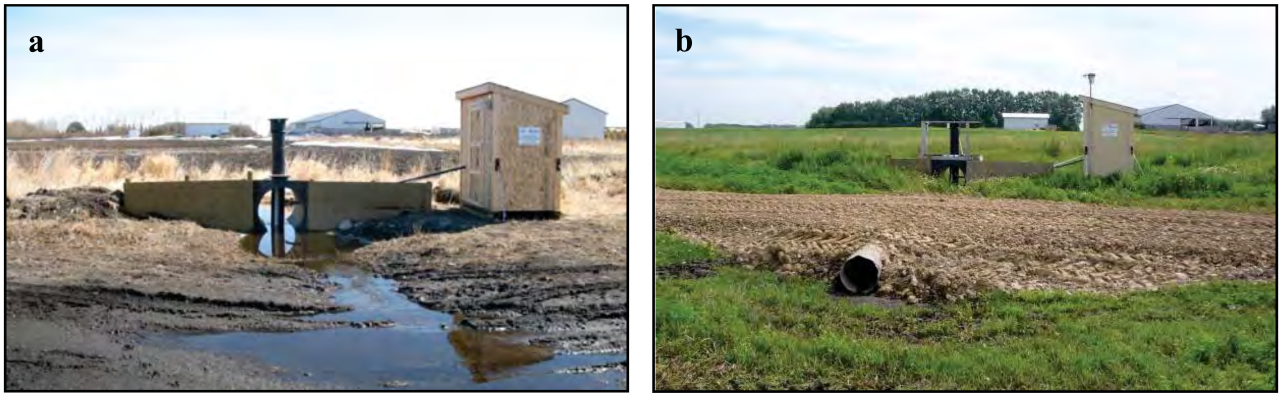

Figure 4.47. Images of the North Field site showing (a) the machinery crossing and eroded area in the field drainage channel in April 2008 and (b) the installed culvert and constructed crossing in July 2010 immediately upstream of Station 311.

Soil-test samples were generally sampled using transects based on field topography (Sub-section 2.9). However in 2010, due to time constraints, soil-test samples were collected in conjunction with the agronomic samples using the 200-m grid. It was assumed that, because of the relatively low topographic relief in the field, the grid method captured adequate variation within the field, and provided representative samples that were comparable to the transect method.

4.7.2.4 Manure Sampling

Liquid manure samples were collected in 2008, 2009, and 2011 and solid manure samples were collected each year from 2007 to 2011. Liquid manure samples were not collected in 2007 and 2010 because the lagoon was emptied before samples could be taken. The number of samples collected per sampling time varied from 2 to 18. Each sample was a composite of several sub-samples. The samples were analyzed for water and nutrient content (Sub-section 2.10).

4.7.2.5 Water Flow and Quality

This site was equipped with three water monitoring stations: Stations 310, 311, and 313. Each station consisted of a circular flume and an automatic Isco water sampler (Sub-sections 2.6, 2.7, and 2.8). Station 311 was an edge-of-field site (Sub-section 2.6) on a small channel within the southwest field, and Stations 310 (downstream) and 313 (upstream) were located on the tributary, which bisected the quarter section in a north-south direction (Figure 4.44). Water quality measurements from all stations at this site were affected by water pooling prior to active flow, particularly during the snowmelt periods. The pooling was caused by very shallow slopes in the landscape and by snow and ice blockage in the tributary. Attempts were made to collect water samples during active flow when pooling was minimal. The pre-BMP period was from 2008 to 2010 and the post-BMP period was in 2011 and 2012.

The original design was to compare the upstream (313) and downstream (210) station to assess BMP effectiveness. Unfortunately, there was poor connectivity between Station 313 and 310 during the per-BMP period (2008 and 2009). As a result, water quality data from Stations 310 and 311 only were used in the assessment of BMPs. Statistical analyses and load calculations are described in Sub-section 2.8.4.

4.7.3 Results and Discussion

4.7.3.1 Implementation of Beneficial Management Practices

On occasion, the implementation of BMPs does not proceed according to the original plan. For the NFD site, the BMP plan was designed to be implemented in fall 2009 by converting from surface-applied to injected liquid manure and the use of a nutrient management plan and setbacks.

However, manure injection equipment was not available in 2009, and in fall 2010, the injection equipment that was available could not inject the manure because the manure contained too much straw. Eventually, manure was successfully injected in 2011 and 2012 (Table 4.33). Manure injected in fall 2011 was within the post-BMP monitoring period. The producer was pleased with the switch to manure injection and continued the practice in fall 2012. However, monitoring for BMP effectiveness ended prior to manure application in fall 2012. As described above, the other components of the BMP plan that were implemented in 2010 included nutrient management plans, setbacks, and erosion control.

As the BMP plan for this site was being developed with the landowner, other components were suggested such as switching the timing of manure application from fall to spring and establishing permanent vegetative cover in the field drainage channels in the northeast and southwest fields during annual crop production. The reasons for not adopting certain BMPs can vary, even when the cost is relatively low, as in the case for these two BMPs. Switching from fall to spring applied manure was not favoured by the producer because of the shorter timeframe available and wetter soil conditions in spring compared to fall. Also, the availability of contracted manure injectors was limited in the spring, especially for small operations such as the NFD site. An alternative option is to inject liquid manure into the alfalfa crops in summer after harvest. A change to summer application would result in the manure being applied after the high rainfall in May and June and access to land when the annually cultivated fields are unavailable. Also, contract manure applicators may be more available during the summer. The establishment of permanent vegetative covers was not favoured because some land would be taken out of production during the annual crop portions of the rotation and the inconvenience of farming around these channels in fields that were already relatively small in size. The main tributary already had grass vegetation, and when in alfalfa, the field channels had permanent cover.

Nutrient management plans were developed in fall 2010 and fall 2011 for manure application. Challenges with the nutrient management plans included (1) not knowing with certainty what annual crop was going to be grown, (2) relying on soil-test results from the previous year (Sub-section 4.7.2.2), and (3) using average nutrient content of manure from previous years (Sub-section 4.7.2.2). The nutrient management plan recommended that no added N and P were required, except for the southwest field when it was converted from alfalfa to annual crop. Following the nutrient management plans would have meant no manure application. However, in practice, the producer had to dispose of manure from the dairy operation each year using a very limited land base. Applying manure to land owned by neighbours would have been an option to meet the recommendations of the nutrient management plan, but this would have required making special agreements and neighbouring land may not have been available each year. As the next best practice, it was decided to continue to apply manure on the annual cropped fields based on the TP removal of the crops. This allowed for manure disposal without causing any further accumulation of P in the soil.

Application rates of manure were calculated for fall 2010 and fall 2011. However, the actual application rates were generally higher (Table 4.35) because of the need to dispose of the stored manure. It was estimated that there was a net addition of TN and TP to the fields based on actual manure rates and nutrient content less the amount of nutrients removed by harvested crop (Table 4.35). Therefore, the goal of matching TP additions from manure to 1 yr of crop removal was not achieved. If the calculated manure rates had been used, the difference between TP additions and removals would have been less or near zero. Total P would have increased by 32 kg ha^{-1} in the northwest field and decreased by 5 kg ha^{-1} in the southeast field in the 2011 crop year. In 2012, a near zero balance would have been achieved with only a 4 kg ha^{-1} TP increase in the southeast field and a 2 kg ha^{-1} TP increase in the southwest field. The calculated manure applications would have also resulted in less TN accumulation. Net balance of TN would have increased by 148 kg ha^{-1} in the northwest field in 2011 and by 37 kg ha^{-1} in the southwest field in 2012. However, TN would have decreased in the southeast field by 11 kg ha^{-1} in 2011 and by 46 kg ha^{-1} in 2012.

The calculated manure application rates (Table 4.35) would have resulted in a closer match between nutrient additions and removals. However, there was still some deviation from a zero balance, particularly for the northwest field in 2011. These deviations were likely the result of assumptions that had to be made at the time the manure rates were calculated including using soil-test results from the previous years, manure nutrient content, crop type, and crop yield.

Table 4.35. Calculated and actual manure application rates, total nitrogen (TN) and total phosphorus (TP) applied in manure, removed by the crop, and estimated net balance for fields at the North Field site during the BMP period.

		Manure rate^z		Applied in manure^y		Removed by crop^x		Estimated net balance^w	
		Calculated	Actual						
		liquid / solid	liquid / solid	TN	TP	TN	TP	TN	TP
Field	Crop	-------- (Mg ha^{-1}) --------		----- (kg ha^{-1}) -----		----- (kg ha^{-1}) ----		--- (kg ha^{-1}) ---	
				2011 crop year					
NW	barley	74 / 13	90 / 21.3	321	64	78	12	243	52
SE	corn	92 / 0	90 / 21.3	321	64	166	29	155	35
				2012 crop year					
SE	barely	0 / 15.5	0 / 22.4	170	40	164	24	6	16
SW	corn	119 / 0	108 / 22.4	361	69	172	30	189	39

^{z} Expressed as wet weights.
^{y} Based on actual manure rates and manure nutrient content (Table 4.39). For liquid manure in the 2011 crop year, TN and TP concentration values were determined as averages of values measured in 2008, 2009, and 2011.
^{x} Based on actual crop yields (Table 4.33) and assumed crop removal values of 17.4 kg Mg^{-1} TN, 2.60 kg Mg^{-1} TP for barley silage and 15.6 kg Mg^{-1} TN, 2.77 kg Mg^{-1} TP for silage corn on a dry-matter basis (Canadian Fertilizer Institute 2001). It was assumed the actual silage yields contained 65% water.
^{w} Estimated net balance = Applied in manure - Removed by crop.

The largest challenge at this site was not enough land to accommodate the nutrients in the manure. Annual soil testing should remain as a primary tool to monitor nutrient status in the fields and to move excess manure to neighbouring cropland if possible.

The overall cost of the BMPs was nearly $5800 and the labour component was not high at 16 h (Table 4.36). The costs in 2010 and 2011 were associated with the culvert installation, materials for construction of the crossing, liquid manure injection, and soil and manure sampling and analysis. The cost to inject the manure was based on the difference between the cost of the injection method and the surface-application method.

4.7.3.2 Soil

Agronomic samples. Extractable NO_3-N concentration in the northwest field was consistently higher in the spring than in the fall (Table 4.37). Manure was applied on the northwest field from 2007 to 2010, allowing NO_3-N concentration to remain fairly stable, with the highest concentration of 74 mg kg^{-1} in spring 2008. After the field was converted to alfalfa in 2011 and manure application ceased (Tables 4.31, 4.32, and 4.33), NO_3-N concentration decreased to 3 mg kg^{-1} by spring 2012. Extractable NH_4-N and STP concentrations fluctuated with no consistent trend with time (Table 4.37). Unlike NO_3-N, STP concentration did not decrease noticeably after conversion to alfalfa and manure application ceased. Additional time may be required to observe a drawdown of STP by crop removal.

Table 4.36. Cost of beneficial management practices at the North Field site.

Item	Cost ($)	Labour (h)
Manure injection[z]	1465.44	-
Soil sampling[y]	616.50	8
Manure sampling[x]	2242.50	4
Nutrient management plan	-	2
Culvert pipe (7.62 m)[w]	373.53	-
Clay and gravel fill material	817.34	-
Trucking	259.88	-
Installation of culvert and fill	-	4
Total	**5775.19**	**16**

[z] This cost was the difference between the cost of manure injection and the cost if the manure was surface applied.
[y] Three samples (0-15, 15-30, 30-60 cm) were submitted each fall in 2010 and 2011, and the cost of analysis was $34.25 per sample.
[x] Twelve and fourteen samples were submitted in fall 2010 and 2011, respectively, and the cost of analysis was $86.25 per sample.
[w] The cost was approximated at $49.02 per metre (Armtec Ltd.).

Table 4.37. Average concentrations for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for the agronomic soil samples (0 to 15 cm) collected from 2007 to 2012 at the North Field site.

	Northwest field			Northeast field			Southeast field			Southwest field		
	NO_3-N	NH_4-N	STP	NO_3-N	NH_4-N	STP	NO_3-N	NH_4-N	STP	NO_3-N	NH_4-N	STP
Season/year	(mg kg^{-1})											
Fall 2007	39	7	79	46	8	64	2	6	53	3	7	48
Spring 2008	74	3	69	89	4	75	3	5	50	7	4	46
Fall 2008	23	6	46	81	5	81	41	5	57	9	5	51
Spring 2009	33	12	96	46	6	63	56	6	77	13	8	46
Fall 2009	24	12	79	37	7	76	23	12	75	8	8	47
Spring 2010	38	6	111	35	7	71	46	7	73	6	6	31
Fall 2010	37	7	77	5	8	77	36	6	94	3	8	32
Spring 2011	27	4	87	20	5	86	29	3	69	2	4	30
Fall 2011	11	6	100	15	7	93	19	5	86	36	7	41
Spring 2012	3	6	74	5	6	64	31	4	93	30	6	31

In the northeast field, NO_3-N concentration was less after spring 2010 compared to the period from fall 2007 to spring 2010 (Table 4.37). As with the northwest field, the lower NO_3-N concentrations after spring 2010 coincided with the conversion from annual crops to alfalfa and the cessation of manure application in 2010 (Tables 4.31, 4.32, and 4.33). The concentrations of extractable NH_4-N and STP were relatively stable with time, and there was no discernable decrease in STP concentration from 2010 to 2012 after manure application ceased.

The opposite effect on NO_3-N concentration was observed for the southeast field when the field was converted from alfalfa to annual crop production after 2008. Under alfalfa and no manure application, NO_3-N concentration was very low in 2007 and 2008 (Table 4.37). After manure application began in fall 2008 and annual crops were grown, NO_3-N concentration increased. Extractable NH_4-N concentration was relatively stable, with values generally less than 8 mg kg^{-1}. Soil-test P concentration responded to manure application from fall 2008 to spring 2012. The lowest STP concentrations were in 2007 and 2008 when the field was under alfalfa. During annual crop production and manure application, STP concentration increased from 53 mg kg^{-1} in fall 2007 to 93 mg kg^{-1} in spring 2012. Variations within this general increase in concentration with time were likely caused by varying amounts of added P in manure and P removed by crops.

In the southwest field, NO_3-N concentration was generally less than 10 mg kg^{-1} from 2007 to 2011 when the field was used for alfalfa production and no manure was applied (Table 4.37). When manure was applied in fall 2011 in preparation for conversion to annual crop production in 2012 (Tables 4.31 and 4.32), the NO_3-N concentration increased by about six-fold compared to the average concentration for the previous years. As with the other three fields, the concentration of NH_4-N was low and relatively stable with time. During the 5 yr of alfalfa production, STP concentration generally decreased from about 48 mg kg^{-1} in fall 2007 to 30 mg kg^{-1} in spring 2011. The slight increase in fall 2011 was likely the result of manure application prior to soil sampling.

The above results show the effects of crop rotation and manure application on NO_3-N and STP concentrations in the top 15-cm soil layer at the NFD site. Clearly, the application of manure caused an increase in NO_3-N and STP concentrations. Nitrate N responded more rapidly than STP. Soil-test P concentration increased when manure was applied, as observed at the southeast field. In contrast, STP concentration was not affected in the short term (i.e., 1 to 2 yr) after manure application ceased at the northwest and northeast fields. However, a decrease in STP concentration was observed at the southwest field where manure had not been applied for a longer period (i.e., 4 yr).

The southwest field had the least amount of manure applied during the study period, and this resulted in lower NO_3-N and STP concentrations. On average for the ten times these parameters were measured, NO_3-N concentration was 12 mg kg^{-1} and STP concentration was 40 mg kg^{-1} at the southwest field. In comparison, average NO_3-N concentration ranged from 30 to 38 mg kg^{-1} and average STP concentration ranged from 73 to 82 mg kg^{-1} among the other three fields. The application of manure at the NFD site resulted in a moderate accumulation of STP greater than the agronomic threshold value of 60 mg kg^{-1} (Howard 2006). The results also showed that having 4 yr of alfalfa in the rotation without manure application can reduce STP concentration to less than the agronomic threshold. However, the fields in annual crop production and with manure application had elevated STP, which may result in more P in runoff water. Reducing the amount of manure applied and better matching the nutrient requirements of annual crops would likely prevent or minimize the increase in STP.

Soil-test samples. Concentrations for NO_3-N, NH_4-N, and STP were similar for all four fields in that the highest concentrations were typically in the 0- to 15-cm soil layer and then decreased with depth (Table 4.38). The decreased in concentration with depth was more prominent for NO_3-N and STP compared to NH_4-N. The concentrations of these three parameters in the 0- to 15-cm layer for the soil-test samples were similar to the fall 2009 and fall 2010 agronomic samples (Table 4.37).

Table 4.38. Soil-test results for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for samples collected at the North Field site in fall 2009 and fall 2010.

Soil	Northwest field			Northeast field			Southeast field			Southwest field		
layer	NO_3-N	NH_4-N	STP	NO_3-N	NH_4-N	STP	NO_3-N	NH_4-N	STP	NO_3-N	NH_4-N	STP
(cm)	(mg kg^{-1})											
							2009					
0-15	19	5	80	28	6	47	23	8	60	7	7	51
15-30	20	4	33	15	5	26	12	5	21	4	6	16
30-60	15	3	11	9	4	10	4	4	5	3	6	5
							2010					
0-15	37	4	75	4	4	76	34	3	76	2	4	23
15-30	5	3	11	2	3	19	3	3	7	1	2	2
30-60	3	3	4	1	3	7	3	3	4	1	3	1

4.7.3.3 Manure

The average nutrient concentration in the liquid dairy manure was less than the concentrations in solid dairy manure on a wet-weight basis (Table 4.39). The nutrient content of the liquid manure was generally consistent among the three sampling occasions. The average concentration of NH_4-N, TN, TP, and TK in the liquid manure samples were less than half the values shown in the 2000 Alberta code of practice for manure management (AFRD 2000).

4.7.3.4 Water Flow and Quality

Water flow. The annual flow in the tributary at the downstream Station 310 varied from 1928 m^3 yr^{-1} in 2009 to nearly 276,000 m^3 yr^{-1} in 2011 (Table 4.40 and Figure 4.48). The two years (2008 and 2009) that had the smallest flow values also had the least amount of total precipitation compared to the other three years (Sub-section 4.2.2). The annual flow at Station 310 was not strictly governed by precipitation. Though the highest annual flow was observed in 2011, total precipitation was actually higher in 2010. The drier conditions in 2008 and 2009 may have resulted in more infiltration in 2010 compared to 2011. Subsequently, antecedent soil moisture may have been higher in 2011, because of the above average precipitation in 2010, and caused more runoff in 2011. On average for the five years, 61% of the annual flow at Station 310 was caused by snowmelt and the remainder was caused by rainfall (Table 4.40). However, the annual proportion caused by snowmelt ranged from very little in 2010 to 100% in 2008 and 2009.

Table 4.39. Average water and nutrient concentration in liquid and solid dairy manure at the North Manure Field from 2007 to 2011.

Sampling date	Number of samples	Water (%)[z]	NH_4-N	Total N	Total P	Total K	Total S	Total Na
			---------- (kg Mg^{-1})[z] ----------					
			Liquid dairy manure					
Aug 23, 2008	2	97	0.95	1.45	0.30	1.35	0.15	0.65
Oct 2, 2009	3	98	0.94	1.47	0.20	1.59	0.15	0.73
Sep 8, 2011	3	96	0.70	1.76	0.27	1.44	0.17	0.59
	Average	97	0.86	1.56	0.26	1.46	0.16	0.66
			Solid dairy manure					
Sep 11, 2007	3	81	1.07	6.87	1.15	4.95	0.97	na[y]
Aug 6, 2008	3	20	0.60	5.32	0.87	4.87	0.62	na
Aug 27, 2008	7	74	2.54	6.15	1.24	5.37	1.42	na
Oct 17, 2008	8	78	0.54	6.29	1.47	6.20	3.23	na
Oct 9, 2009	18	76	0.81	8.01	1.59	8.35	1.96	na
Oct 21, 2010	12	70	0.71	8.49	1.89	9.42	1.81	na
Sep 13, 2011	11	76	0.58	7.61	1.78	6.75	1.35	na
	Average	68	0.98	6.96	1.43	6.56	1.62	na

[z] Values expressed on a wet-weight basis.
[y] na = not analyzed.

There was a lack of flow connectivity between upstream Stations 313 and the downstream Station 310 during the pre-BMP years (2008 and 2009) and in 2012, particularly for snowmelt. However, there was good flow connectivity between Stations 313 and 310 during rainfall in 2010 and 2011 (Figure 4.48). The annual flow at Station 313 was 18,424 m^3 yr^{-1} in 2010 and 155,842 m^3 yr^{-1} in 2011. These flow values measured at Station 313 were 76 and 56% of the annual flow measured at Station 310 in 2010 and 2011, respectively. The lack of connectivity during years with lower flow was cause by the relatively shallow slope of the tributary. A survey of the bottom of the tributary was carried out in October 2008, starting about 50 m upstream from Station 313 to just downstream from Station 310 (about 485 m in total length). The survey showed little slope in the tributary, and the tributary was relatively level from Station 313 to about 215 m downstream. Then from this reach to Station 310 (about 240 m) the slope was more noticeable, but was still quite shallow at less than 0.02%. The tributary upstream from the confluence with the west field drainage channel (i.e., Station 311) was essentially flat, resulting in pooled water at Station 313 and into the east field drainage channel during low flow conditions. Also, snow and ice during snowmelt occasionally blocked or limited the flow and contributed to the pooling of water.

Annual flow at the edge-of-field Station 311 ranged from 53 to 58,378 m^3 yr^{-1} and followed a similar pattern as Station 310, with the smallest flow in 2009 and the largest flow in 2011 (Table 4.40 and Figure 4.48). In 2008, the annual flow at Station 311 was nearly the same as the flow at Station 310, suggesting that most of the flow at Station 310 originated from area that drained through Station 311. However, in the other four years, the annual flows at Station 311 were smaller proportions compared to Station 310, ranging from 3 to 33%. In 2010, the annual flow at Stations 311 and 313 accounted for all of the annual flow at Station 310; whereas in 2011, the combined annual flows at Stations 311 and 313 was about 78% of the annual flow at Station 310. On average for the five years, 75% of the annual flow at edge-of-field Station 311 was caused by snowmelt, with values that ranged from 12 to 100% (Table 4.40).

Table 4.40. Annual flow and proportions attributed to snowmelt and rainfall runoff at the edge-of-field Station 311, and tributary Station 310 at the North Field site from 2008 to 2012.

	Annual flow		Proportion as snowmelt		Proportion as rainfall	
	Station 311	Station 310	Station 311	Station 310	Station 311	Station 310
Year	--------- (m^3 yr^{-1}) ---------		--------- (%) ---------		--------- (%) ---------	
2008 (pre-BMP)	6,354	6,623	99	100	1	0
2009 (pre-BMP)	53	1,928	100	100	0	0
2010 (post-BMP)	7,882	24,144	12	0.2	88	99.8
2011 (post-BMP)	58,378	275,938	65	32	35	68
2012 (post-BMP)	4,603	60,565	98	74	2	26

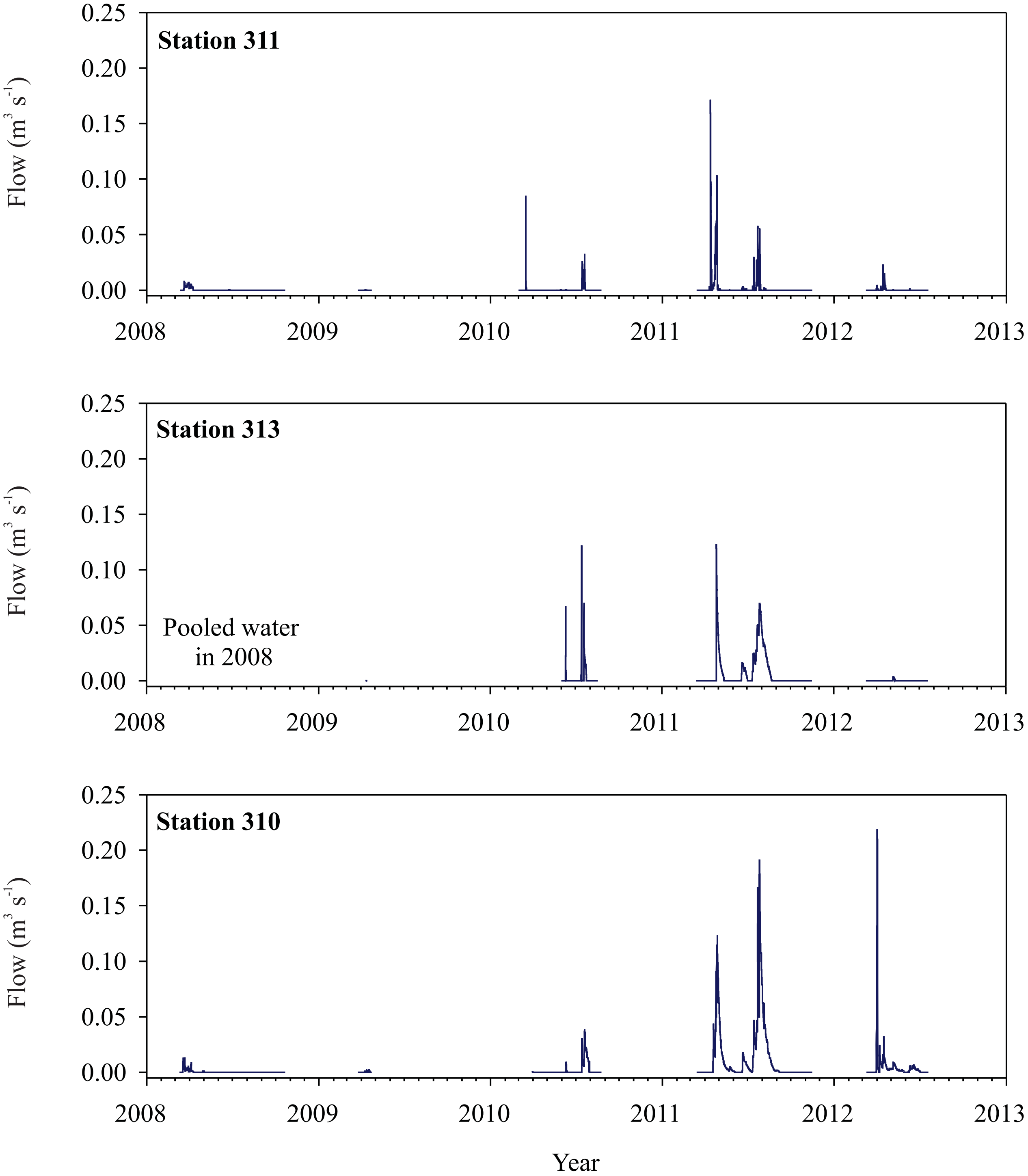

Figure 4.48. Hydrographs for Stations 311 (edge-of-field), 313 (upstream), and 310 (downstream) at the North Field site from 2008 to 2012.

General water quality observations. The concentrations of nearly all water quality parameters were higher at Station 311 (edge-of-field) compared to the tributary instream Stations 310 and 313, especially during snowmelt events (Table 4.41). Higher concentrations at edge-of-field stations were typical at other BMP sites in the project where edge-of-field and instream water quality were monitored. During rainfall events, the average concentration for all years of most parameters (N, TP, PP, Cl, and *E. coli*) was higher at the downstream Station 310 compared to the upstream Station 313 on the tributary. The reverse was true for PP and TSS, suggesting settlement of sediment material in the shallow tributary. During snowmelt events, the increase in average concentrations from upstream to downstream was not as consistent as compared to rainfall events. Of all the parameters, the average concentration of *E. coli* increased the most from upstream to downstream in snowmelt (42-fold increase) and in rainfall (3.6-fold increase) events.

The concentrations of N parameters were generally higher during snowmelt compared to rainfall, averaged for all years (Table 4.41). The concentration of NO_3-N in particular ranged from 2-fold greater at Station 311 to nearly 8-fold greater at Station 313. Exceptions included ON at Stations 311 and 310 and NH_3-N at Station 310 for which average concentrations were higher in rainfall. The average concentration of all P parameters, TSS, and *E. coli* were consistently higher during rainfall events compared to snowmelt. This was also the case of Cl and EC at Stations 313 and 310. The much higher *E. coli* concentrations in rainfall events was caused by the warmer conditions, which favoured microbial activity compared to the colder snowmelt conditions.

On average, TN was generally comprised mostly of ON during rainfall and snowmelt events at all three monitoring stations (Table 4.41). For example, TN at Station 310 was 61% ON in snowmelt and 83% ON in rainfall, average for the study period. An exception was for snowmelt at Station 313 where ON and dissolved inorganic N (NO_3-N plus NH_3-N) concentrations were nearly equal. Among individual samples, the concentration of TN ranged from 1.6 to 46 mg L^{-1}, with peak concentrations at Station 310 in 2009, 2010, and 2012, and at Station 2011 in 2011 (Figure 4.49a). The concentration of TN appeared to decrease at Station 310 from 2009 to 2012.

The proportion of TP as TDP ranged from 73 to 89% among the three stations and two runoff event types, averaged for the study period (Table 4.41). Among individual samples, the concentration of TP ranged from 0.29 to 4.4 mg L^{-1}. As with TN, the highest TP concentration observed during the study was at Station 311 in 2011, which was also the year with the highest annual flow (Table 4.40).

The concentration of TSS among samples ranged from 1.5 to 1250 mg L^{-1} during the study period (Figure 4.49c). Peak concentrations occurred at Station 311 in 2008 and 2009 and at Station 313 in 2010. It is interesting that 2011, which had the highest annual flow, did not have peak TSS concentrations. It is often expected that with higher flows erosion and movement of sediment in runoff may be higher. The maximum concentrations ranged only from 12 to 109 mg L^{-1} among the three stations in 2011 (Figure 4.49c).

Table 4.41 . Average concentration of water quality parameters at Stations 313 (upstream), 310 (downstream), and 311 (edge-of-field) at the North Field site from 2008 to 2012.[z]

Year (n)[y]	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli* (mpn 100 mL^{-1})	EC (μS cm^{-1})	pH
	(mg L^{-1})											
					Station 313 (Snowmelt)							
2008 (10)	11.2	3.57	5.69	1.81	1.03	0.93	0.10	16	n/a[x]	1	493	7.70
2009 (2)	8.61	4.70	2.40	1.17	1.57	1.23	0.35	81	39.0	19	469	7.67
2011 (15)	3.52	2.36	1.08	0.08	0.66	0.54	0.12	6	22.4	1	301	7.67
2012 (2)	3.90	3.79	0.03	0.12	1.39	1.25	0.14	48	25.2	1	414	7.61
All (29)	6.55	3.04	2.69	0.76	0.90	0.77	0.13	17	24.5	2	386	7.68
					Station 310 (Snowmelt)							
2008 (10)	4.62	4.32	0.04	0.24	1.16	0.98	0.19	5	n/a[x]	245	436	7.65
2009 (2)	32.0	8.06	22.1	0.46	1.95	1.48	0.47	8	101	66	804	7.65
2011 (15)	3.26	2.15	1.09	0.04	0.61	0.57	0.04	2	19.8	1	309	7.71
2012 (2)	4.36	3.77	0.50	0.10	1.23	1.18	0.06	3	46.2	1	506	7.73
All (29)	5.79	3.42	2.13	0.14	0.94	0.82	0.12	4	34.7	84	400	7.69
					Station 311 (Snowmelt)							
2008 (20)	6.25	5.07	0.15	0.97	1.33	1.14	0.22	34	n/a[x]	372	451	7.65
2009 (3)	6.01	3.22	1.88	0.71	1.20	1.07	0.12	8	18.4	329	307	7.76
2010 (2)	6.95	3.76	1.29	1.80	2.92	2.75	0.17	12	12.4	1,220	292	7.54
2011 (20)	6.40	3.46	2.27	0.62	1.52	1.35	0.18	5	24.3	1	323	8.02
2012 (10)	17.9	7.53	9.15	0.78	1.96	1.78	0.18	6	123	1	924	8.81
All (55)	8.44	4.78	2.69	0.83	1.56	1.39	0.19	16	51.3	188	477	8.00
					Station 313 (Rainfall)							
2010 (13)	5.28	4.14	0.79	0.32	1.55	0.89	0.66	242	35.9	7,276	457	7.71
2011 (19)	2.94	2.75	0.06	0.14	1.05	0.93	0.12	15	37.6	217	437	7.68
2012 (2)	2.53	2.40	0.03	0.13	0.55	0.28	0.28	39	72.0	1	546	7.61
All (34)	3.81	3.26	0.34	0.21	1.21	0.88	0.33	104	39.0	2,985	451	7.69
					Station 310 (Rainfall)							
2010 (13)	4.89	3.60	0.69	0.50	1.23	1.07	0.16	9	39.3	19,513	419	7.71
2011 (19)	3.90	3.44	0.17	0.28	1.37	1.22	0.16	9	38.2	5,803	462	7.76
2012 (2)	2.97	2.93	0.03	0.03	0.55	0.48	0.07	3	74.0	401	643	7.94
All (34)	4.22	3.47	0.36	0.35	1.27	1.12	0.15	9	41.4	10,877	456	7.75
					Station 311 (Rainfall)							
2008 (2)	7.44	3.68	3.58	0.13	0.90	0.68	0.22	50	n/a[x]	60,000	568	8.10
2010 (15)	4.30	3.48	0.61	0.16	2.46	2.09	0.36	84	8.06	2,132	271	7.74
2011 (21)	5.65	4.00	1.31	0.32	2.01	1.78	0.23	19	16.5	803	408	7.72
2012 (2)	3.81	2.49	1.13	0.12	1.44	1.17	0.28	50	26.0	409	449	8.08
All (40)	5.14	3.71	1.15	0.24	2.10	1.81	0.28	46	13.7	4,242	366	7.76

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Number of samples is shown in parentheses. Concentration averages do not include days where sampling methods (grab and ISCO) were different at Stations 313 and 310.
[x] Chloride was not included until late July 2008.

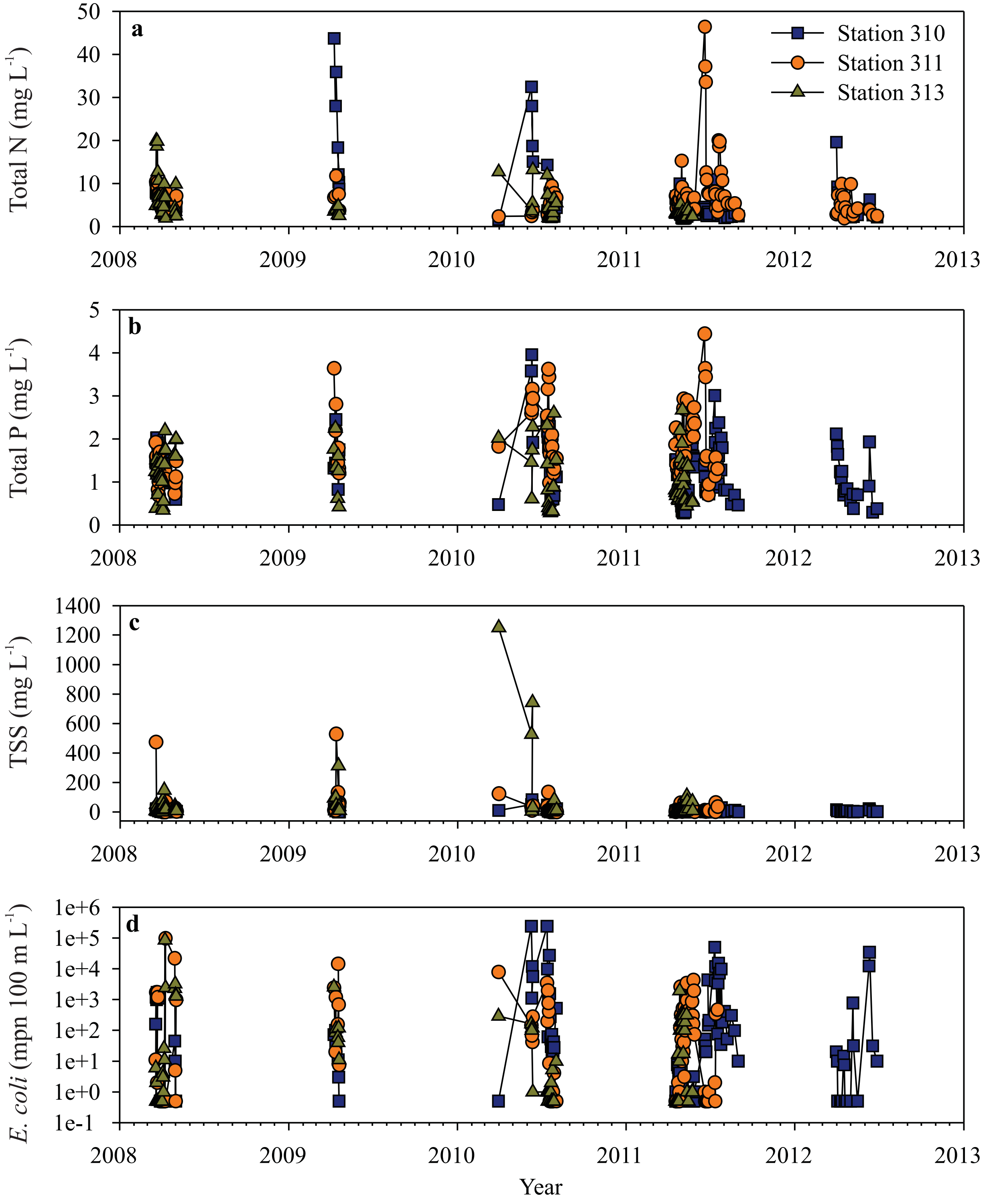

Figure 4.49. Concentrations of (a) total nitrogen (Total N) (b) total phosphorus (Total P), (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) at Stations 310, 311, and 313 at the North Field from 2008 to 2012.

The largest *E. coli* concentrations were 98,000 mpn 100 mL^{-1} at Station 311 in June 2008, 86,640 mpn 100 mL^{-1} at Station 313 in June 2010, and 241,960 mpn 100 mL^{-1} at Station 310 in June and July 2010 (Figure 4.49d).

Annual loads of nutrients and TSS at the downstream Station 310 were greatest in 2011 compared to the other years, ranging from 1.1- to 859-fold greater among the parameters (Table 4.42). The larger loads in 2011 corresponded to the largest annual flow, which was also observed in 2011 (Table 4.40). In the same context, the smallest loads were in the year (2009) that had the smallest annual flow. Generally, annual loads increased with annual flows at Station 310. The annual flow in 2011 was 143-fold greater than in 2009. In comparison, annuals loads among the parameters were 25- to 859-fold greater in 2011 compared to 2009. The variation in load increases among the parameters relative to the increase in flow from 2009 to 2011 suggests an influence of concentrations in terms of higher or lower values in 2011 compared to 2009. For example, average TN concentration was about 10-fold less in 2011 compared to 2009 (Table 4.41), resulting in a relative load increase (25-fold) that was less than the annual flow increase in 2011 (143-fold) compared to 2009.

BMP effects on water quality. At the downstream station (Station 310) for all events combined, the average concentrations of TN, ON, NH_3-N, TP, TDP, PP, and *E. coli* were significantly reduced in the post-BMP period compared to the pre-BMP period (Table 4.43). Decreases among these parameters ranged from 19% for TDP to 81% for *E. coli*. Lower values were also observed for NO_3-N, Cl, and EC in the post-BMP period, but they were not significantly different from the pre-BMP period. Lower concentrations in the post-BMP period compared to the pre-BMP period were observed for snowmelt and rainfall events. The differences between the two periods were statistically significant for most parameters in snowmelt; whereas, only the concentration of *E. coli* was significantly reduced during rainfall events in the post-BMP period. In contrast, EC was significantly increased in the post-BMP period during rainfall events.

At the edge-of-field station (Station 311), differences between the pre- and post-BMP periods were not as consistent as observed at Station 310. For the two runoff event types combined, the concentration of TSS and *E. coli* were reduced significantly by 76 and 92%, respectively, from the pre-BMP period to the post-BMP period (Table 4.44). In contrast, the concentrations of TN, NO_3-N, Cl, and pH were significantly higher in the post-BMP period compared to the pre-BMP period. The remaining parameters were not significantly different between the two periods.

Table 4.42. Water quality parameter loads at Station 310 at the North Field site from 2008 to 2012. [z]

Year	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
	(kg yr^{-1})							
2008	41	34	0.27	6.9	9.4	8.0	1.4	76
2009	52	13	36	0.9	2.9	2.3	0.6	14
2010	104	81	14	7.0	34	30	4.1	282
2011	1029	749	232	44.5	342	312	29.2	2101
2012	564	266	254	40.1	86.8	77.0	9.83	488

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids.

Table 4.43. Average runoff water quality parameters measured at Station 310 at the North Field site in the pre-BMP and post-BMP periods.[z]

Event	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli*	EC	pH
		($mg\ L^{-1}$)									(mpn 100 mL^{-1})	($\mu S\ cm^{-1}$)	
						Snowmelt							
Pre-BMP[y]	33	8.74*a*	4.88*a*	3.28*a*	0.47	1.32*a*	1.14*a*	0.18*a*	8*a*	73.3*a*[x]	241	489*a*	7.71
Post-BMP	33	4.78*b*	2.83*b*	1.68*b*	0.24	0.97*b*	0.90*b*	0.07*b*	4*b*	28.0*b*	3	366*b*	7.72
						Rainfall							
Pre-BMP	21	7.37	5.25	1.04	0.96	1.67	1.38	0.29	17	38.3	25,954*a*	466*b*	7.70
Post-BMP	39	3.69	3.38	0.14	0.18	1.21	1.08	0.13	7	46.9	4,101*b*	520*a*	7.79
						All events							
Pre-BMP	54	8.21*a*	5.02*a*	2.41	0.66*a*	1.46*a*	1.24*a*	0.22*a*	12*a*	47.9	11,491*a*	480	7.71
Post-BMP	72	4.19*b*	3.13*b*	0.85	0.21*b*	1.10*b*	1.00*b*	0.10*b*	6*b*	38.2	2,196*b*	451	7.76

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Average BMP phase concentrations per parameter followed by letters are significantly different at $P < 0.1$.
[x] Chloride was not included until late July 2008, resulting in only eight samples sample for the pre-BMP period.

Table 4.44. Average runoff water quality parameters measured at Station 311 at the North Field site in the pre-BMP and post-BMP periods.[z]

Event	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli*	EC	pH
		($mg\ L^{-1}$)									(mpn 100 mL^{-1})	($\mu S\ cm^{-1}$)	
						Snowmelt							
Pre-BMP[y]	25	6.28*b*	4.75	0.45*b*	1.01	1.44	1.26	0.21	29*a*	16.0*b*[x]	443*a*	421	7.65*b*
Post-BMP	30	10.3*a*	4.82	4.57*a*	0.68	1.67	1.49	0.18	6*b*	57.2*a*	1*b*	523	8.28*a*
						Rainfall							
Pre-BMP	17	4.67	3.51	0.96	0.16	2.27	1.93	0.35	80*a*	8.06*b*[x]	8940	306*b*	7.78
Post-BMP	23	5.49	3.86	1.30	0.30	1.96	1.73	0.24	21*b*	17.4*a*	769	411*a*	7.75
						All events							
Pre-BMP	42	5.63*b*	4.24	0.65*b*	0.66	1.78	1.54	0.27	50*a*	10.0*b*	4147*a*	374	7.71*b*
Post-BMP	53	8.18*a*	4.40	3.15*a*	0.51	1.80	1.59	0.20	12*b*	39.9*a*	334*b*	475	8.05*a*

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Average BMP phase concentrations per parameter followed by letters are significantly different at $P < 0.1$.
[x] Chloride was not included until late July 2008, resulting in five samples for snowmelt and 15 samples for rainfall in the pre-BMP period.

The above results for Station 310 (downstream) clearly support the hypothesis that implemented BMPs would improve water quality. The BMPs at this site included P-based manure application, manure set-backs, injected liquid manure, relocation of a manure storage area, and erosion control. As previously indicated, the application of manure based on crop removal of P was not always achieved and higher rates were applied. Also, the switch from surface-applied to injected liquid manure only occurred in 2011 and only on one field (southwest field). The producer injected manure in fall 2012; however, this was after the monitoring period for the project. If liquid manure continues to be injected rather than surface applied, and if lower manure application rates can be achieved by moving excess manure off the farm, the effectiveness of these BMPs on improving water quality is expected to be enhanced.

The results at the edge-of-field Station 311 were less conclusive. However, the significant reduction of TSS by 76% from pre- to post-BMP (Table 4.44) suggests the erosion control measures of installing a culvert and constructing a raised crossing through the drainage channel was effective. This BMP was practical to implement and relatively inexpensive. The channel leading to Station 311 drained the southwest field (Figure 4.44). This field was in alfalfa for four years (2008 to 2011) of the five-year study, with no manure application in 2007 to 2010. Manure was applied in fall 2011 in preparation for switching the rotation to corn in 2012. The injection of liquid manure in the southwest field in early September 2011 resulted in little surface disturbance. However, later in September and October, the field was tilled with discs, solid manure applied, and the manure incorporated with a cultivator (Table 4.33). Therefore, the surface condition of the field leading into 2012 was quite difference than in the previous four years of continuous alfalfa. The significantly higher TN and Cl concentrations observed at Station 311 in the post-BMP period may have been caused by the change in field-surface conditions and the addition of manure, particular the solid manure. In fact, within the post-BMP period (2011 and 2012), the average concentration of TN in snowmelt increased from 6.4 mg L^{-1} in 2011 to 17.9 mg L^{-1} in 2012; and similarly, Cl increased from 24.3 to 123 mg L^{-1} (Table 4.41). The increase in TN concentration was the result of higher ON and NO_3-N concentrations. Similar increases were not observed for rainfall runoff at Station 311 in 2012. In contrast, the concentration of P was largely unaffected between the pre- and post-BMP periods, and between 2011 and 2012 snowmelt at Station 311. It is interesting that TSS concentration did not increase because presumably, the extensive tillage carried out on the southwest field in fall 2011 would have made the soil surface more susceptible to erosion. Also interesting was the significant reduction in *E. coli* concentration from the pre- to post-BMP periods at Station 311, considering that manure was not applied during the pre-BMP period and applied in 2011 during the post-BMP period. Finally, the manure set-backs used in the southwest field in fall 2011 were along the main tributary (i.e., along the east side of the field) and would have had very little effect on water quality at Station 311.

The accumulated improvement of the BMPs on water quality was realized for the whole NFD site as shown by the results from Station 2010. However, the results at Station 311 demonstrated the challenges of trying to evaluate the effectiveness of BMPs when conditions change that can mask or confound effects, which in this case for the southwest field was the conversion of alfalfa to annual crop production. Ideally, a field in annual crop production with several years of surface application of liquid manure followed by years of injected manure would have provided better experimental conditions to evaluate this BMP. However, because of the complicated crop rotation among the four fields at this site and the timeframe available for the study, some factors could not be controlled at an individual field scale.

4.7.4 Conclusions

- After three years (2008 to 2010) of pre-BMP monitoring, most of the BMP plan was successfully implemented at the NFD site, except for switching from surface-applied to injected liquid manure, which was delayed until fall 2011. The implemented BMPs included a nutrient management plan, manure application based on crop removal of P, manure setbacks, manure storage relocation, and erosion control.
- Manure was applied at a higher rate than what was recommended in the BMP plan because of insufficient land to accommodate the amount of manure produced. The export of manure off the farm would be required in order to accommodate P-based application of manure at this site under the current crop rotation.
- The application of manure caused an increase in concentrations of NO_3-N and STP in soil. Nitrate N concentration responded more rapidly than STP concentration in terms of increases when manure was applied and decreases when manure application ceased. After manure application ceased, STP concentration remained stable in the short term (i.e., 1 to 2 yr), likely because of residual P. However, a decrease in STP concentration was observed when manure had not been applied for a longer period under alfalfa production (i.e., 4 yr).
- On average for the five years, 61% of the annual flow at downstream Station 310 was caused by snowmelt. The annual proportion caused by snowmelt ranged from very little in 2010 to 100% in 2008 and 2009. At the edge-of-field Station 311, 75% of the annual flow was caused by snowmelt.
- Because of the shallow slope of the drainage channel, water often pooled and at times lacked connectivity in the pre-BMP years. Also, snow and ice during snowmelt occasionally either blocked or limited the flow and contributed to the pooling of water.
- The concentrations of nearly all water quality parameters were higher at edge-of-field (Station 311) compared to the tributary (Stations 310 and 313), especially during snowmelt events.
- The erosion control measures of installing a culvert and constructing a raised crossing through the drainage channel upstream from Station 311 (edge-of-field) resulted in a significant reduction of TSS by 76% from the pre-BMP period to post-BMP period.
- The conversion of the southwest field from alfalfa to annual crop production at the same time of implementing the change from surface-applied to injected liquid manure made results at Station 311 inconclusive in terms of BMP effect. For example, TN and Cl concentrations were significantly higher during the post-BMP period, and may have been the result of the surface-cover change and manure application (i.e., from alfalfa to corn). Plus *E. coli* concentration was significantly higher during the pre-BMP period even though no manure was applied during this period and manure was applied in the post-BMP period. The results from Station 311 and the change in field conditions (crop rotation) in the southwest field demonstrated some of the challenges of evaluating BMPs at the field scale.

- During rainfall events, the average concentration for all years of most parameters (N, TP, PP, Cl, and *E. coli*) was higher at the downstream Station 310 compared to the upstream Station 313 in the tributary. The reverse was true for PP and TSS, suggesting settlement of sediment material in the shallow tributary. During snowmelt events, the increase in average concentrations from upstream to downstream was not as consistent as compared to rainfall events.
- On average, TN was generally comprised mostly of ON during rainfall and snowmelt events, with values of 61 and 83% as ON, respectively at the downstream Station 310. The proportion of TP as TDP ranged from 73 to 89% among the three stations and two runoff event types.
- At the downstream station (Station 310), the average concentrations of TN, ON, NH_3-N, TP, TDP, PP, and *E. coli* were significantly reduced (19 to 81%) in the post-BMP period compared to the pre-BMP period, supporting the hypothesis that implemented BMPs would improve water quality at this site.

4.8 East Field

4.8.1 Introduction and Hypotheses

The EFD was one of the four manure nutrient BMP sites in the WHC Sub-watershed. The site received annual manure applications on barley crops in 2006 and 2007. Then the field was in alfalfa production from 2008 to 2012, and manure was not applied in 2008 and 2009. This change in crop sequence created difficulties in selecting manure nutrient BMPs, and thus none were implemented. Even though BMPs could not be assessed at this site, the conversion of the field to alfalfa provided an opportunity to assess the risk on runoff water quality of applying liquid manure to a perennial forage crop.

Perennial crops, such as alfalfa, offer benefits of decreased soil erosion and nutrient loss from surface runoff compared to annual crops. Permanent crops are typically not tilled nor often receive manure. However, perennial crops do provide an opportunity to increase the land base for the utilization of manure; plus, perennial forages use more nutrients than annual crops. In a recent survey of dairy producers in Alberta, it was reported that only about one-third of dairy producers applied manure to forage crops (Trevor Wallace, ARD 2009, personal communication). Forage crops are important for dairy operations and manure can serve as a cost-effective source of nutrients.

The surface application of liquid manure on perennial crops would be considered a higher environmental risk compared to no application of manure. Therefore, manure application during the forage phase of a crop rotation would not be considered a BMP. Nevertheless, circumstances at this site provided an opportunity for an environmental assessment of liquid manure application on an alfalfa crop. Even though, in this case, the application of liquid manure was not considered a BMP, practices were used to minimize the environmental risk including (1) P-based application rates, (2) setbacks from an in-field drainage channel, and (3) choice of equipment to apply the manure directly on the soil surface to facilitate infiltration and to avoid aerial exposure. Since BMPs were not implemented at this site, economics were not assessed. Additionally, comparisons of alfalfa yields between fields with and without manure were performed.

The underlying assumption was that applying liquid manure on a forage crop without incorporation would increase the risk of nutrient and bacteria loss during surface runoff as compared to when no manure was applied. The hypotheses were:

- The surface application of liquid dairy manure on an alfalfa crop using drag tubes, application rates based on crop P removal, and use setbacks would have a negative impact on water quality parameter concentrations in runoff at this site compared to no manure application.
- The application of liquid dairy manure will result in a positive yield response by alfalfa.

4.8.2 Methods

4.8.2.1 Site Description and Management

The EFD site was located near the central area of the sub-watershed (Figure 4.3). This field was divided into two parts by a WHC tributary, which flowed east-northeast from the southwest corner of the field (Figure 4.50). The tributary was a relatively deep incised channel with a wooded poplar (*Populus spp*.) riparian area (Figure 4.51). The field north of the tributary was 41 ha in size and the area south was 18 ha in size. The runoff-contributing areas on either side of the tributary were approximately 26 and 14 ha, respectively.

The northwest corner of the EFD quarter section was in the same AGRASID soil landscape model (CYLP1/U1h) as described for the WFD (Alberta Soil Information Centre 2013) (Sub-section 4.6.2.1). The remainder of the EFD quarter section was in the same AGRASID soil landform model (CYLP2/U1hc) as described for a portion of the NFD site (Sub-section 4.7.2.1). The surface soil at the site had a loam texture (36% sand, 16% clay), a pH of 5.8, electrical conductivity of 0.3 dS m^{-1}, 2870 mg kg^{-1} TN, 752 mg kg^{-1} TP, and 6.4% organic matter (Appendix 4).

The landowner had farmed this field for 15 yr and also owned the SFD site (Sub-section 4.9). Crops grown on this field were rotated between perennial alfalfa/grass and annual crops. For the duration of this study, the field was mainly use to grow alfalfa and grass. In May 2007, the entire field was seeded to barley using an air drill, while 28 ha at the north end were under-seeded (broadcasted) with alfalfa (Table 4.45). The field was tilled with a disc cultivator prior to seeding and was followed by harrows and rollers in 2007. In May 2008, alfalfa was under-seeded to a barley crop on the rest of the field. From 2009 to 2012, the entire field was in alfalfa and 5% timothy grass. From 2009 to 2012, granular fertilizer was broadcasted on the alfalfa crop in late April (Table 4.45). Achieve® herbicide was sprayed on the barley crop on June 20, 2008, and Roundup® herbicide was applied on September 1, 2009 to desiccate the crop for harvest. Roundup® was also used to desiccate 31 ha of alfalfa on the south end of the field on September 17, 2012.

The barley crop was harvested as silage on August 5, 2007 and as feed grain on September 17, 2008. From 2009 to 2012, alfalfa was typically harvested three times per year as silage, except in 2009 when it was harvested twice. The first cut was from late June to early July, the second cut was in mid-August, and the third cut was from late October to early November. The third cut of silage was plastic-wrapped as bales. Total annual wet yields for alfalfa from 2008 to 2012 ranged from 14.6 to 29.9 Mg ha^{-1} (Table 4.45).

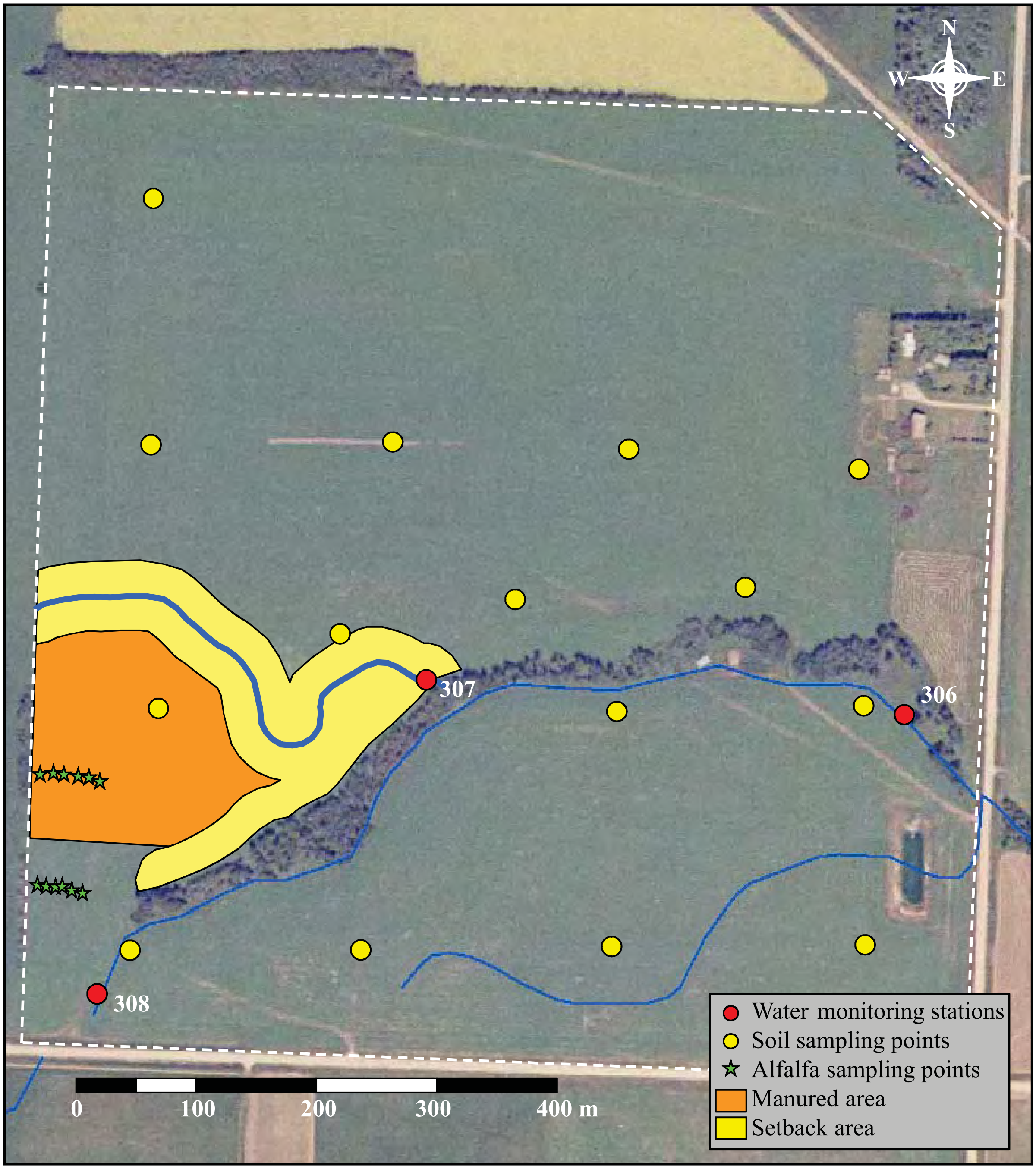

Figure 4.50. The East Field site showing the three water monitoring stations (Stations 306 307, and 308), soil and alfalfa (2010) sampling points, and the area where manure was applied with setbacks for the runoff water quality study from 2010 to 2012.

Figure 4.51. The tributary at the East Field with a relatively deep incised channel and a wooded poplar (*Populus spp*.) riparian area in April 2008.

In 2007, the owner had a dairy operation with a herd consisting of 185 milking cows, 23 dry cows, 68 heifers, 139 calves, and 55 cull cows. The dairy produced mostly liquid manure, using free-stall housing with canola straw bedding for the milking cows. Liquid dairy manure had been applied annually to some areas of the EFD site. This manure was surface applied to the entire field at a rate of 62 Mg ha^{-1} in the fall of 2006 and on 31 ha of barley stubble in fall 2007, and was incorporated into the soil using a cultivator. Manure was not applied in 2008 and 2009. Liquid dairy manure was surface applied on 34 ha from August 23 to 26, 2011 at a rate of 67.4 Mg ha^{-1}. The application area included everything south of the tributary and 16 ha on the west portion of the field north of the tributary.

Table 4.45. Management practices at the East Field site from 2007 to 2012. [z]

Year	Area (ha)	Crop	Seeding date	Harvest date	Yield (Mg ha^{-1})	Commercial fertilizer N	P	K	S	Manure application Date	Rate (kg ha^{-1})
						-------- (kg ha^{-1}) --------					
2007[y]	28	barley[x,w]	May 13-14	Aug 3	6	na[v]	na	na	na		
	31[u]	barley	May 15	Sep 17	3.2	na	na	na	na	Oct 15[t]	62
2008	28	alfalfa	-	June 30	14.4						
				Aug 8	13.0						
				Oct 16[s]	1.0						
	31	barley[x,r]	May 19-23	Aug 8	23.5	59	39	39	39		
2009[q]	59	alfalfa	-	June 25	4.5 - 5.6	0.4	0.3	0.3	0.3		
				Aug 10	9.0 - 10.0						
2010[p]	59	alfalfa	-	June 30	15.5	16	49	24	6	July 5-6[o]	57
				Aug 11	10.8						
				Nov 6[s]	3.6						
2011[n]	59	alfalfa[m]	-	July 2	15.5	16	49	24	6	July 8-9[o]	59
				Aug 22	10.8						
				Nov 10[s]	2.9 - 3.3					Aug 23-26[l]	67.4
2012[k]	59	alfalfa	-	July 3	15.5	16	49	24	6		
				Aug 14	10.8						
				Oct 17[s]	0.1						

[z] Not all dates are exact.
[y] Seeding preceded by disc tillage at a depth of 12.5 to 15 cm and followed by harrows and rollers.
[x] Under-seeded with alfalfa in 2007 on 28 ha at the north side of the field and in 2008 to the rest of the field (31 ha).
[w] Unknown rate and blend of fertilizer applied with seed.
[v] na = not available.
[u] Barley sprayed with Achieve® on June 20 and desiccated with Roundup® on September 1. Crop was swathed on September 10 and harvested as feed grain. Sixty percent of the straw was baled on September 17and yielded 80 straw bales at 363 kg per bale.
[t] Incorporated with disc cultivation at a depth of 10 cm.
[s] Removed as bales.
[r] 196 kg ha^{-1} of 30-20-20-20 applied with seed. S as sulphate, not elemental S.
[q] 2.8 kg ha^{-1} of 13-12-12-12 applied on April 21.
[p] 135 kg ha^{-1} of 11.8-36.4-18-4.8 applied on April 22.
[o] On 3 ha in the drainage area of the edge-of-field Station 307.
[n] 135 kg ha^{-1} of 11.8-36.4-18-4.8 applied on April 28.
[m] Alfalfa crop on 31 ha of south end of field was desiccated with Roundup® on September 17.
[l] All of the area south of tributary plus 16 ha on the west portion north of the tributary (34 ha in total).
[k] 135 kg ha^{-1} of 11.8-36.4-18-4.8 applied on April 28.

4.8.2.2 Liquid Manure Application Studies

Two liquid manure application studies were carried out at this site. One was a small-plot study and the other was an edge-of-field runoff water quality study using Station 307.

Small-plot study. A small-plot liquid manure application study was carried out to compare alfalfa yields with different manure application methods and rates in 2009. The plots were established about 150 m north of the drainage channel at the EFD site on August 19, 2009 (Figure 4.50), which was 9 d after the second cut of the alfalfa crop. A total of 12 plots, each 4 by 45 m in size, were arranged in a series of six paired plots (Figure 4.52), with each pair of plots including a manure application treatment plot and an adjacent control plot with no manure application. The liquid dairy manure application treatments included two application implements (trail hose and AerWay®) and three application rates (16,850; 33,700; and 50,550 L ha^{-1}). Manure density was assumed to be about 1 kg L^{-1}, and the application rates were expressed by rounding to the nearest Mg ha^{-1} (17, 34, and 51 Mg ha^{-1}, respectively). For the adjacent control plots, the tractor and application implements were simply driven over the plots without applying manure. Manure samples were collected for nutrient content analysis. On October 2, five forage samples were harvested from each plot. Alfalfa samples were harvested from square areas (0.5 by 0.5 m) at distances of 5, 14, 23, 32, and 40 m within each plot. Samples were cut near to the ground, bagged, weighed, and then oven dried. After 5 d of drying, the samples were re-weighed and dry-weight yields in megagrams per hectare were determined. Yield differences were calculated by comparing the average yield from manure plot to the average yield from the adjacent control plot within each pair of plots. Because this was not a true randomized replicated plot experiment, statistical analysis could not be performed.

Runoff water quality study. This study was carried out on a portion of the area drained by the field channel associated with Station 307 (Figure 4.50). Setbacks, 30-m wide along the drainage channel and tributary were used where no manure was applied. The setback width along the drainage channel was measured from the centre of the channel. The area that received manure was about 3 ha in size. Even though the application of liquid manure was not considered a BMP in this case, practices were used to minimize the associated environmental risks. P-based application rates

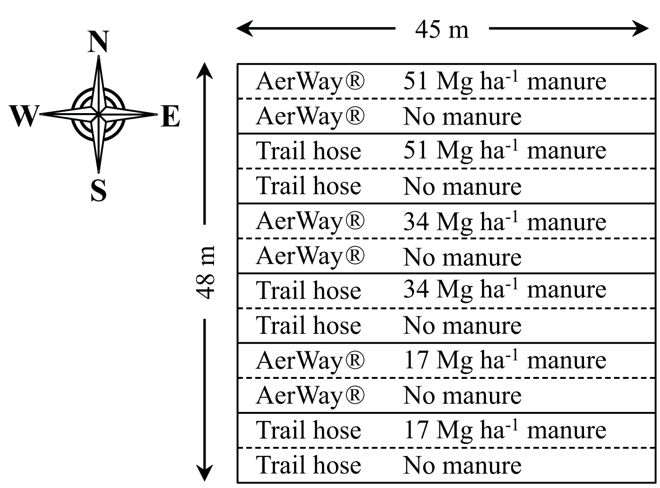

Figure 4.52. Plot design of the manure application study carried out at the East Field in 2009.

were used to prevent accumulation of STP and application setbacks along the in-field drainage channel were used to minimize nutrient transport to the creek.

Soil samples collected at the site in fall 2009 and fall 2010 showed that soil-test NO_3-N was low (less than 3 mg kg^{-1}) and STP was not excessive (about 70 mg kg^{-1}) in the 0- to 15-cm layer (Subsection 4.8.3.1). Results from the AFFIRM program showed that the EFD site did not require added N or P in 2010 or 2011. Therefore, in order to avoid further P accumulation, liquid dairy manure was applied based on one year of P crop removal. To calculate the application rates, a typical alfalfa yield was assumed, P removal estimates were based on values from the Canadian Fertilizer Institute (2001), and manure nutrient content was based on previous samples collected at the EFD and SFD sites as both sites were owned by the same producer and used the same source of manure.

The manure rates applied to the 3-ha area were 34.8 Mg ha^{-1} in 2010 and 71 Mg ha^{-1} in 2011. Manure application in both years was carried out in early July shortly after the first alfalfa harvest, in order to minimize crop damage from the field equipment. The manure was applied using drag tubes with Aerway® technology in order to place the liquid directly on the soil surface and to promote infiltration (Figure 4.53). The combination of drag tubes and Aerway® technology was expected to minimized manure contact with plants, reduce odour, and reduce N loss through volatilization.

Alfalfa yield was determined prior to the second and third harvest cuts in 2010. Two transects were laid out starting from the west side of the field (Figure 4.50). One transect was located 60 m north from the south edge of the manure-applied area, and the other transect was located in a non-manured area about 40 m south of the manured area. The first samples were taken on August 9, 2010, 1 d before the second cut of alfalfa and 34 d after manure was applied. The second samples

Figure 4.53. Manure applicator using drag tubes with AerWay® technology used for applying liquid dairy manure on alfalfa at the East Field site in July 2010 and 2011.

were taken on September 27, 26 d before the third cut. Six, square (0.5 by 0.5 m) forage samples were harvested from each transect, at the 10-, 20-, 30-, 40-, 50- and 60-m marks. Samples were cut by hand near the ground surface, bagged, and then oven dried at 50 to 55 °C. After drying, the samples were weighed and the average dry-weight yields were calculated. Yield differences were calculated by comparing the average yield from manure transect to the average yield from the non-manure transect for each cut. A Mann-Whitney paired test was used to determine if the sample sets were significantly different ($P < 0.1$).

Yield from the manured and non-manured areas were not compared in 2011 because the producer surface-applied liquid manure on the field in August 2011 before the second cut, including the manured and non-manured areas used for the runoff water quality study.

4.8.2.3 Soil Sampling

Soil characterization samples (Sub-section 2.9) were collected on December 2, 2009. Soil samples collected annually at this site were the 0- to 15-cm agronomic samples (2007 to 2012). Other samples collected at this site included soil-test samples in 2009 and 2010.

Agronomic samples at this field site were collected using a grid with extra sample sites added to cover the drainage area more effectively. There were a total of 15 sample points at this field site (Figure 4.50).

Soil-test samples were generally sampled using transects based on field topography (Sub-section 2.9). However, because of time constraints in 2010, these samples were collected in conjunction with the agronomic samples using the grid. It was assumed that the relatively low topographic relief of the field allowed the grid sites to adequately capture variations within the field and provide representative samples comparable to the transect method.

4.8.2.4 Manure Sampling

Liquid dairy manure samples were collected once annually in 2007, 2009, and 2011. The 2009 samples were collected for the small-plot study (Sub-section 4.8.2.2). Samples were analyzed for water and nutrient content (Sub-section 2.10).

4.8.2.5 Water Flow and Quality

The EFD site was equipped with three water monitoring stations: Stations 306, 307, and 308 (Figure 4.50). Station 308 was located upstream on the tributary, near the southwest corner of the quarter section. Station 306 was downstream, at the exit point on the east side of the quarter section. Station 307 was an edge-of-field monitoring station located at the point of discharge of a channel draining part of the field northwest of the tributary. The area that drained towards Station 307 was about 16.7 ha in size on the northwest side of the tributary, including 10 ha of the field west of the EFD site. All three stations included a circular flume and an automatic Isco water sampler (Sub-sections 2.6, 2.7, and 2.8).

The purpose of the tributary stations was to compare upstream-downstream differences for water-quality parameter concentrations between the pre-manure (2008 to 2010) and post-manure (2011 and 2012) application periods in the runoff water quality study. The purpose of Station 307 was to compare water-quality parameter concentrations between the pre- and post-manure application periods. However, because of low and non-connective flow between the upstream and downstream stations, water samples could not be collected for analysis in several of the study years. Additionally, some water samples were collected using the grab sampling method when the automatic Isco samplers could not be used. Only samples collected by the same method on the same day for the upstream and downstream stations were compared. As a result, no useful pre-manure application water-quality data were collected from Stations 306 and 308. Therefore, these two stations could not be used for pre- and post-manure application comparisons. At Station 307, only one year (2011) had runoff caused by rainfall. Therefore, only snowmelt runoff at the edge-of-field Station 307 was used to assess the effects of manure application. Statistical analysis and load calculation are described in Sub-section 2.8.4.

4.8.3 Results and Discussion

4.8.3.1 Soil

Agronomic samples. Extractable NO_3-N and NH_4-N concentrations were generally higher in the spring than the fall (Table 4.46). The highest NO_3-N concentration in the fall was in 2007 and the highest concentration in the spring was in 2008. These higher values were likely caused by the application of dairy manure in fall 2007. However, the manure that was applied in 2010 and 2011 (Table 4.45) had no effect on extractable soil N. In July 2010 and 2011, manure was applied to only a small portion (3 ha) of the field and this amount would not have affected the average nutrient content of the entire field. Also, NO_3-N supplied by the manure application was likely utilized by the alfalfa crop, which was harvested twice prior to fall soil sampling in both years. The manure applied by the producer in August 2011 was on 57% of the field and a third harvest of the alfalfa crop occurred after manure application and prior to fall soil sampling.

Extractable NH_4-N and STP concentrations were fairly consistent among years, fluctuating during the study period with no definite trend. Soil-test P concentrations for spring and fall averaged 68 mg kg^{-1} (Table 4.46), which was slightly greater than the agronomic threshold of 60 mg kg^{-1} (Howard 2006). The concentration of STP remained relatively constant because the alfalfa crop received annually about 50 kg ha^{-1} P in the form of commercial fertilizer (Table 4.45).

Soil-test samples. The concentrations of NO_3-N, NH_4-N, and STP in the 0- to 15-cm soil layer for the soil-test samples (Table 4.47) were similar to the values for the fall 2009 and 2010 agronomic soil samples (Table 4.46). The concentration of NO_3-N and STP decreased with soil depth; whereas, the concentration of NH_4-N was more consistent with soil depth (Table 4.47).

4.8.3.2 Manure

The liquid dairy manure contained 96% water on average (Table 4.48). Average TN concentrations were less than the range of 3.5 to 6.0 kg Mg^{-1} reported in the Manure Characteristics and Land Base Code (AFRD 2006) used for AOPA (Province of Alberta 2010). Total P and K concentrations were about half of the values reported by AFRD (2000).

4.8.3.3 Water Flow and Quality

Water flow. The highest annual flow was in 2011 at all three monitoring stations (Table 4.49). The second and third highest annual flows occurred in 2012 and 2008, respectively. The high flow in 2011 was cause by greater than normal precipitation (Figure 4.5). In low-flow years (2009 and 2010), water did not reach far beyond the flume at Station 308 and did not reach the wooded part of the tributary. The wooded part of the tributary started about 80 m downstream from Station 308. The wooded portion of the tributary had dense undergrowth and plant residues. There was also a berm across the tributary between Stations 307 and 306. The berm and plant residues in the tributary likely restricted water movement, particularly during low-flow events. There often was no connective flow between Stations 308 and 306. For example, small amounts of water flowed at Station 308 in 2009 and 2010; whereas, there was no flow at Station 306 during these two years. In

Table 4.46. Average concentrations for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for the agronomic soil samples (0 to 15 cm) collected from 2007 to 2012 at the East Field site.

	NO_3-N[z]		NH_4-N		STP	
	Spring	Fall	Spring	Fall	Spring	Fall
Year	(mg kg^{-1})					
2007	ns[z]	8.2	ns	9.2	ns	49
2008	36.4	2.9	7.8	3.4	70	79
2009	6.0	0.8	11.1	4.3	65	67
2010	3.1	3.8	5.4	4.2	76	74
2011	7.2	4.0	6.5	3.9	67	67
2012	7.7	ns	8.5	ns	61	ns

[z] ns = not sampled.

Table 4.47. Nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) concentrations in the soil-test samples collected at the East Field in the fall 2009 and 2010.

	NO_3-N		NH_4-N		STP	
Soil layer	2009	2010	2009	2010	2009	2010
(cm)	(mg kg^{-1})					
0 to 15	1.7	3.6	4.8	2.9	70	68
15 to 30	0.7	1.5	3.8	1.7	34	14
30 to 60	0.3	1.0	3.1	2.5	13	7

Table 4.48. Average water and nutrient content in liquid dairy manure applied to the East Field site.[z]								
	Number	Water	NH_4-N	Total N	Total P	Total K	Total S	Total Na
Sampling date	of samples	(%)	--------------------------------	--------------------------------	(kg Mg^{-1})	--------------------------------	--------------------------------	
Oct 12, 2007	3	95	1.67	2.63	0.40	1.83	0.23	0.20
Aug 19, 2009	2	98	1.19	1.71	0.21	2.70	0.17	0.42
Jul 8, 2011	3	95	1.82	3.26	0.56	2.72	0.28	0.42
	Average	96	1.56	2.53	0.39	2.42	0.23	0.35

[z] Values are expressed on a wet -weight basis.

the 3 yr when flow occurred at the upstream and downstream stations, annual flow was 1.5- to 2.5-fold greater at Station 308 compared to Station 306. This suggests that a large proportion of the water may have seeped or infiltrated into the soil prior to reaching Station 306. There was also the possibility that flow at Station 308 may have been overestimated because of pooled water.

The flow at edge-of-field Station 307 was much smaller compared to the two tributary stations. The annual flow at Station 307 ranged from 1 to 24% of the annual flow measured at 306 in 2008, 2011, and 2012. Similar to Station 308, water that flowed through Station 307 did not reach Station 306 in 2009.

Using the relative contributions of snowmelt and rainfall reported in Table 4.49, it was calculated that 84 and 67% of the total 5-yr volume of water through Stations 308 and 306, respectively, was caused by rainfall. In contrast, 38% of the total 5-yr volume of water through Station 307 was caused by rainfall. Annual flow was proportioned between snowmelt and rainfall events in 2011 and 2012. In the other 3 yr, flow was either caused entirely by snowmelt or entirely by rainfall (Table 4.49). In 2010, water from rainfall was retained in the field and no flow occurred at Station 307 (Figure 4.54).

Table 4.49. Annual flow and proportion of flow caused by snowmelt and rainfall at Stations 308 (upstream), 307 (edge-of-field), and 306 (downstream) at the East Field from 2008 to 2012.

	Station 308			Station 307			Station 306		
Year	Annual flow (m^3 yr^{-1})	Proportion as snowmelt (%)	Proportion as rainfall (%)	Annual flow (m^3 yr^{-1})	Proportion as snowmelt (%)	Proportion as rainfall (%)	Annual flow (m^3 yr^{-1})	Proportion as snowmelt (%)	Proportion as rainfall (%)
2008	6,400	100	0	750	100	0	3,140	100	0
2009	101	100	0	226	100	0	0	0	0
2010	450	0	100	0	0	0	0	0	0
2011	986,199	13	87	21,517	70	30	392,769	24	76
2012	87,413	40	60	802	100	0	59,135	41	59

Flow in the tributary typically occurred in the spring (March to June) and runoff from the field occurred in March and/or April (Figure 4.55). However, because of the extensive precipitation in 2011, flow in the tributary continued from July to early September and runoff from the field occurred in July.

General water quality observations. The average (all years) concentrations of water-quality parameters during snowmelt and rainfall events were similar between the two tributary stations (Stations 306 and 308) (Table 4.50). This suggests that contributions from the surrounding field had little effect on the quality of water as it moved from upstream to downstream. However, as indicated above, the movement of water in the tributary was not connective in years with low flow. Though in 2011, which had high flow at both stations, the water chemistry between the two stations were still quite similar. Also, the distance was relatively short (about 750 m) between Stations 308 and 306 (Figure 4.50) with no obvious source (e.g., direct cattle access, degraded riparian zone) that may contribute to water-quality degradation.

Compared to the two tributary stations, the edge-of-field station (Station 307) had higher average (all years) concentrations of N and P parameters, TSS, and *E. coli* for snowmelt (Table 4.50). This was also true for P parameters, TSS, and *E. coli*, but not for N parameters, for rainfall runoff at Station 307. In contrast, average Cl concentration and EC were less at Station 307 in snowmelt and rainfall runoff compared to Stations 306 and 308.

Figure 4.54. Pooled rainfall water at the East Field on July 14, 2010.

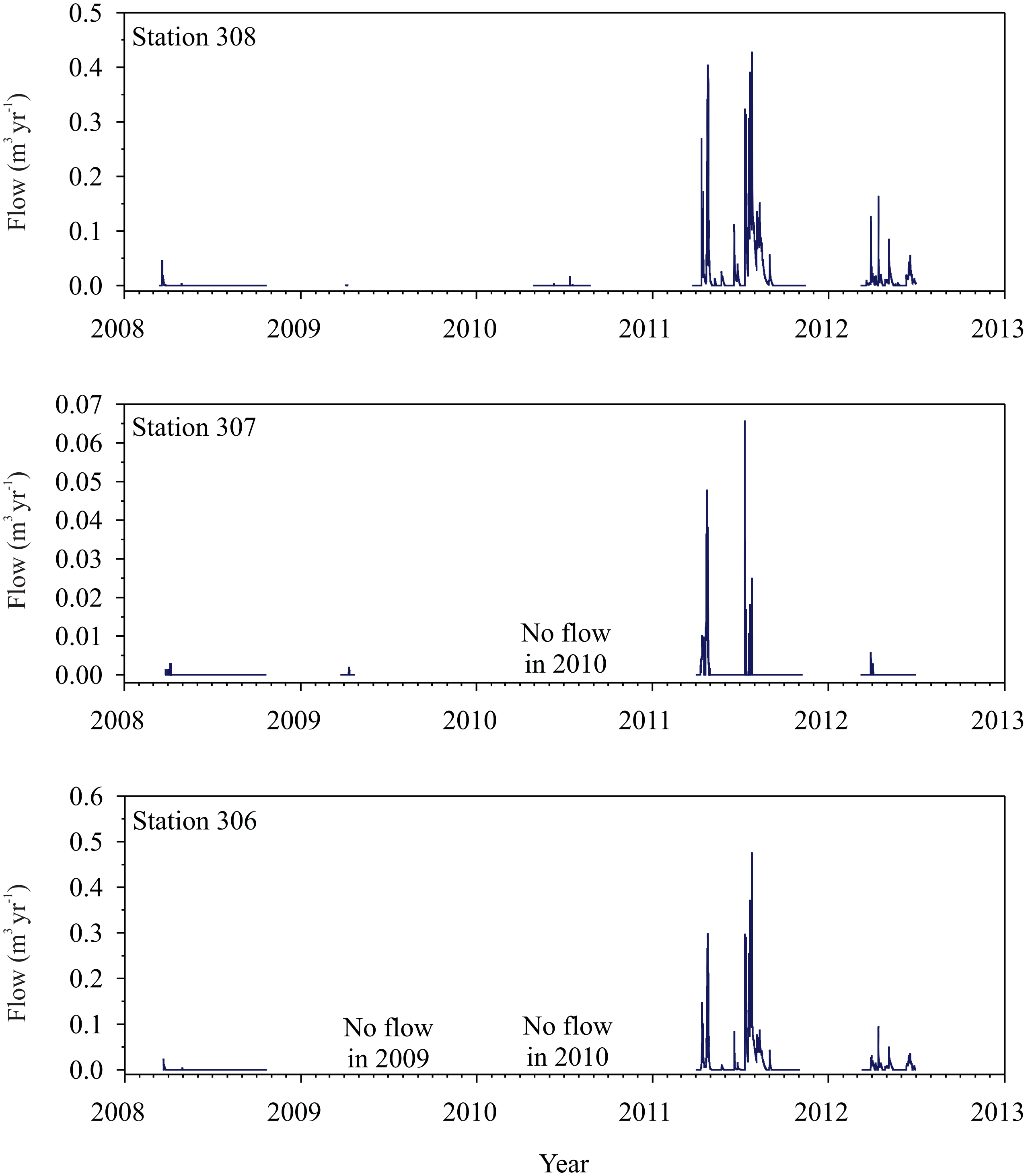

Figure 4.55. Hydrographs for tributary upstream (Station 308), edge-of-field (Station 307), and downstream (Station 306) stations at the East Field from 2008 to 2012.

Generally, the average (all years) concentrations of N and P parameters, TSS, and Cl were higher during snowmelt than during rainfall events at all three monitoring stations (Table 4.50). An exception was for PP and TSS at Station 307, which had lower concentrations during snowmelt compared to rainfall. However, only 1 yr (2011) of water-quality data was collected during rainfall at this station. On average, *E. coli* concentration during snowmelt was 2 to 3% the concentrations measured during rainfall. The lower concentrations during snowmelt were likely caused by less microbial activity due to lower temperatures. Electrical conductivity was also less during snowmelt at Stations 306 and 308 compared to rainfall; whereas, the opposite was true at Station 307.

During snowmelt, the majority (69 to 77%) of TN was in the form of DIN (NO_3-N plus NH_3-N) (Table 4.50). However, in rainfall events, only 13 and 17% of TN was in the form of DIN at Stations 308 and 306, respectively. The portion of TN as DIN was even less (6%) at Station 307. Possibly during snowmelt, particulate forms of N were less available for movement in water due to frozen surface conditions. In contrast, the majority of TP was in the form of TDP at all three stations for snowmelt and rainfall events. The proportion of TP as TDP was higher for snowmelt (93 to 94%) compared to rainfall (76 to 90%) among the three stations. The lowest average percentage of TP as TDP (76%) was at Station 307.

Because of the much larger annual flow in 2011 compared to the other years, the loads of nutrients and TSS in edge-of-field runoff were also much larger in 2011 at Station 307 (Table 4.51). The annual flow was similar between 2008 and 2012 at Station 307 (Table 4.49), and the year with the higher load varied among the parameters. The smallest loads were observed in 2009, which also had the smallest annual flow, and no flow occurred in 2010.

Table 4.50. Average water quality parameter concentrations at Stations 308 (upstream) and 306 (downstream) at the East Field site from 2008 to 2012.[z]

Year[y]	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli*	EC	pH
	------------------------------				(mg L^{-1})			------------------------------		(mpn 100 mL^{-1})	(µS cm^{-1})	
					Station 308 (Snowmelt)							
2008 (6)	4.40	2.83	1.28	0.24	1.00	0.95	0.10	6	na[x]	4	382	7.82
2011 (20)	10.7	2.51	7.62	0.53	0.68	0.61	0.06	12	19.9	13	310	7.61
2012 (12)	11.0	3.68	5.54	1.73	1.63	1.53	0.10	8	34.7	8	522	7.96
All (38)	9.80	2.93	5.96	0.86	1.03	0.96	0.08	10	25.4	10	388	7.75
					Station 306 (Snowmelt)							
2008 (6)	5.22	3.06	1.99	0.11	1.22	1.22	0.04	4	na	11	374	7.83
2011 (20)	9.54	2.42	6.30	0.78	0.71	0.66	0.05	6	16.5	5	275	7.59
2012 (12)	9.92	3.18	5.31	1.40	1.33	1.26	0.08	6	29.7	10	461	7.79
All (38)	8.98	2.76	5.31	0.87	0.99	0.93	0.06	6	21.5	7	350	7.69
					Station 307 (Snowmelt)							
2008 (7)	31.1	3.12	23.8	4.03	3.30	3.16	0.14	26	n/a[y]	3	385	7.30
2009 (1)	4.82	2.28	0.26	2.25	0.43	0.34	0.09	13	0.97	1	69	7.50
2011 (15)	9.54	2.78	4.34	2.34	1.11	1.06	0.05	3	9.95	1	198	7.46
2012 (6)	8.74	5.05	0.10	3.59	1.98	1.79	0.19	11	9.15	385	251	7.38
All (29)	14.4	3.31	8.03	3.00	1.79	1.69	0.10	10	9.33	83	250	7.41
					Station 308 (Rainfall)							
2011 (30)	2.74	2.49	0.22	0.03	0.59	0.54	0.06	6	18.1	387	433	8.15
2012 (8)	3.29	2.53	0.72	0.03	0.20	0.15	0.05	5	34.9	13	564	8.17
All (38)	2.85	2.50	0.33	0.03	0.51	0.46	0.06	5	21.6	314	460	8.15
					Station 306 (Rainfall)							
2011 (30)	2.58	2.27	0.28	0.03	0.57	0.52	0.05	5	18.4	404	422	8.03
2012 (8)	3.28	2.25	0.99	0.03	0.21	0.18	0.03	4	34.5	1094	546	8.07
All (38)	2.73	2.26	0.43	0.03	0.50	0.44	0.05	5	21.8	539	448	8.03
					Station 307 (Rainfall)							
2011 (8)	1.87	1.78	0.08	0.03	1.01	0.77	0.24	30	3.28	4149	119	7.50

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

[y] Number of samples are shown in parenthesis. Parameter concentration averages in this table include days where the sampling methods (grab and ISCO) were different at Station 306 and 308, so no statistical comparisons were made.

[x] This parameter was added late in July 2008.

Table 4.51. Annual loads of nutrients and total suspended solids in runoff at Station 307 at the East Field from 2008 to 2012.

Year	TN[z]	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
	(kg yr^{-1})							
2008	23.8	2.31	18.3	3.08	2.53	2.41	0.12	23
2009	1.09	0.52	0.06	0.51	0.10	0.08	0.02	3
2010	0	0	0	0	0	0	0	0
2011	153	52.5	72.6	26.5	21.7	19.0	2.72	318
2012	7.78	4.36	0.07	3.34	1.61	1.43	0.18	11.0

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids.

4.8.3.4 Liquid Manure Application Studies

Small-plot study. Dry-weight alfalfa yield ranged from 4.0 to 4.5 Mg ha^{-1} in the manure application treatments (Table 4.52). An increase in alfalfa yield of 10.9% compared to the control plots was measured for the highest manure concentration (51 Mg ha^{-1}) for both application methods. Yield difference relative to the controls was less for the other two manure application rates, with a slight yield reduction for the AerWay® at 17 Mg ha^{-1} and the trail hose at 34 Mg ha^{-1}. There was no clear difference between the two application implements. Because of the lack of treatment replication, statistical analysis could not be performed. However, the results suggest that at least more than 34 Mg ha^{-1} of liquid dairy manure is required to obtain a yield response by alfalfa at this site.

Runoff water quality study. The manure application rate calculated to provide 1 yr of TP crop removal was 34.8 and 71 Mg ha^{-1} for 2010 and 2011, respectively. The actual application rate was 57 Mg ha^{-1} in 2010 because the ground speed of the application equipment was too slow. Because of application equipment failure, the actual rate applied in 2011 was 59 Mg ha^{-1}, and only 2.2-ha of the intended 3-ha received manure.

Table 4.52. Effects of liquid dairy manure and application equipment on forage crop dry-weight yield at the East Field site in late summer 2009.

Amount of manure applied[z] (Mg ha^{-1})	Application method	Dry-weight yield (Mg ha^{-1})[y]	Yield change relative the adjacent control plot[x] (Mg ha^{-1})	Yield change (%)
17	Trail hose	4.4	0.3	7.8
17	AerWay®	4.0	-0.3	-6.3
34	Trail hose	4.3	-0.2	-3.8
34	AerW ay ®	4.0	0.1	3.0
51	Trail hose	4.0	0.4	10.9
51	AerWay®	4.5	0.5	10.9

[z] Dairy liquid manure applied August 19, 2009.
[y] Averages of five samples collected from each plot.
[x] Positive number is a yield increase, and negative number is a yield decrease.

The application rate for 2010 was calculated based on alfalfa yield in 2009. As it turned out, the yield in 2010 (29.9 Mg ha^{-1}) was much higher than in 2009 (about 14.5 Mg ha^{-1}; Table 4.45) and more TP was likely removed than was applied by manure. The alfalfa crop was harvested twice in 2009 versus three times in 2010. Also, the first harvest yield in 2009 was low due to less than average precipitation from April to June 2009 (Sub-section 4.2.2). When the actual yield in 2010 was used to re-calculate the manure application rate, an application rate of 77.5 Mg ha^{-1} could have been required to match 1 yr of crop P removal.

Dry-matter yield of alfalfa were not significantly different between the manured and non-manured areas (Table 4.53). The lack of a yield response to manure was not consistent with the results from the small-plot study in 2009. The results from the small-plot study suggested a yield response when 51 Mg ha^{-1} of liquid manure was applied (Table 4.52). However, an application of 57 Mg ha^{-1} in 2010 did not result in a significant yield response (Table 4.53), and therefore, the hypothesis of an expected yield increase was rejected.

The concentrations of TN, NO_3-N, NH_3-N, TP, TDP, TSS, and EC in snowmelt runoff at Station 307 were significantly less in the post-manure application period (2011 and 2012) compared to the pre-manure application period (2008 to 2010) (Table 4.54). Only *E. coli* concentration had the opposite result, and this was caused by a single high concentration (2247 mpn 100 mL^{-1}) on March 30, 2012. Three parameters (ON, PP, and pH) were not significantly different between the pre- and post-manure periods. These results showed that liquid manure application to alfalfa did not increase nutrient and TSS concentrations in surface runoff during snowmelt compared to when no manure was applied. As a result, the hypothesis was rejected and applying liquid manure under the conditions at this site resulted in no risk to runoff water quality. The reason why there was no negative impact may be due to the use of setbacks, applying manure based of crop P requirements, and the type of application equipment used. It should be noted that some of the manure applied by the landowner in August 2011 (Table 4.45) was applied on the western portion of the field north of the tributary, and this also did not seem to have a negative effect on runoff water quality (Table 4.54).

The significant reduction in concentration of several parameters (TN, NO_3-N, NH_3-N, TP, TDP, TSS, and EC) was likely caused by the change in manure application and crop rotation, and not related to the liquid manure trial. The concentrations of TN, NO_3-N, TP, and TDP in snowmelt runoff at Station 307 were much higher in 2008 than in the other years (Table 4.50). This may have been the result of the manure application in fall 2007. The application of no manure in 2008 and

Table 4.53. Average (n = 6) alfalfa dry-matter yield from square half-metre samples collected at the East Field site in 2010.

Harvest date	Treatment	Dry-matter yield (Mg ha^{-1})[z]
August 9, 2010	Manure	3.1*a*
	Non-manure	3.7*a*
September 27, 2010	Manure	1.9*a*
	Non-manure	1.8*a*

[z] For each sampling date, averages followed by the same letter are not significantly different ($P < 0.1$).

Table 4.54. Average water quality parameter concentrations during the pre-manure (2008 to 2010) and post-manure (2011 and 2012) periods for snowmelt runoff at Station 307 at the East Field.[z]

Period	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	*E. coli*	EC	pH
		-------------------------				($mg\ L^{-1}$)			-------------------------	(mpn 100 mL^{-1})	($\mu S\ cm^{-1}$)	
Pre-manure	8	27.9*a*[y]	3.02	20.9*a*	3.81*a*	2.94*a*	2.81*a*	0.14	24*a*	2*b*	345*a*	7.33
Post-manure	21	9.31*b*	3.43	3.13*b*	2.70*b*	1.35*b*	1.27*b*	0.09	5*b*	110*a*	213*b*	7.44

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Averages for each parameter followed by letters are significantly different (P <0.1).

2009, along with the conversion from cereal to alfalfa production likely resulted in the lower concentrations in the post-manure period (2011 to 2012) compared to the pre-manure period (2008 to 2010).

These results do not necessarily suggest that, in general, surface application of liquid manure on perennial forages would have no risk to water quality. In this study, manure application was compared only to no manure application. Additional studies would be required to assess whether or not the use of setbacks, P-based application rates, and type of application equipment had a positive effect. Comparisons to other manure application conditions (e.g., no setbacks, higher application rates) would be required to make this assessment.

4.8.4 Conclusions

- Because the EFD site was converted from annual crop to alfalfa production early in the study, an assessment of BMPs was not possible. However, this site did provide an opportunity to assess the potential risk to runoff water quality from liquid manure application on alfalfa.
- After conversion to alfalfa, soil extractable NO_3-N became very low; whereas, STP concentration remained slightly greater than the agronomic threshold of 60 mg kg^{-1}. The concentration of STP was maintained with annual application of commercial inorganic fertilizer.
- Annual flow in the tributary was often not connective between the upstream (Station 308) and downstream (Station 306) stations, particularly during low flow. Annual flow was higher at the upstream station compared to the downstream station, suggesting seepage along the tributary.
- Annual flow at the edge-of-field station (Station 307) was 1 to 24% of the annual flow at Station 306 in the 3 yr when flow occurred at both stations.
- In 2011 and 2012, annual flow was proportioned between snowmelt and rainfall events. In the other 3 yr, flow was either caused entirely by snowmelt or entirely by rainfall. Flow at the tributary stations was dominated by rainfall; whereas, runoff at the edge-of-field station was dominated by snowmelt.

- Flow in the tributary typically occurred in the spring (March to June) and runoff from the field typically occurred in March and/or April.
- The average (all years) concentrations of water-quality parameters during snowmelt and rainfall events were similar between the two tributary stations suggesting that contributions from the surrounding field had little effect on the quality of water in the tributary.
- The edge-of-field station had higher average (all years) concentrations of N and P parameters, TSS, and *E. coli* for snowmelt events compared to the tributary stations. This was also true for P parameters, TSS, and *E. coli*, but not for N parameters, for rainfall runoff at the edge-of-field station.
- Generally, the average (all years) concentrations of N and P parameters, TSS, and Cl were higher during snowmelt than during rainfall events at all three monitoring stations, except for PP and TSS at Station 307.
- The majority (69 to 77%) of TN was in the form of DIN during snowmelt; whereas, in rainfall events, only 6 to 17% of TN was in the form of DIN. The majority (76 to 94%) of TP was in the form of TDP at all three stations for snowmelt and rainfall events.
- Though statistical analysis could not be carried out, yield results from the 2009 small-plot study suggested no difference between the trail hose and AerWay® manure application equipment. The results also suggested no yield response by alfalfa when manure was applied at 17 and 34 Mg ha^{-1}, and nearly an 11% yield increase when manure was applied at 51 Mg ha^{-1}. In contrast, there was no alfalfa yield response when manure was applied at 57 Mg ha^{-1} during the runoff water quality study in 2010.
- Because of the lack of connectivity between the two tributary stations and only 1 yr of rainfall runoff at the edge-of-field station (Station 307), only snowmelt data from Station 307 could be used to assess the impacts of liquid manure application in the runoff water quality study.
- The runoff water quality study showed that the application of liquid dairy manure on alfalfa using setbacks along the drainage channel, applying manure based on crop P requirements, and applying manure directly on the soil surface did not increase the risk to runoff water quality compared to no manure application at this site.

4.9 South Field

4.9.1 Introduction and Hypotheses

The SFD was one of the four manure nutrient BMP sites in the WHC Sub-watershed. The field was in annual crop production from 2007 to 2012 during the study. Liquid dairy manure was surface applied annually in the spring to the field and incorporated. The soil nutrient data did not indicate an over-application of manure as the nutrient concentrations were not excessive. The BMPs were implemented in April 2010 and included a manure nutrient management plan and manure application setbacks. The site had three water monitoring stations: two to monitor run-on into the field and one to monitor runoff from the field.

The assumption underlying the choice of the BMPs was that the application of manure without a nutrient management plan or setbacks would increase the loss of nutrients in snowmelt and rainfall runoff at this site. The hypothesis was:

- The implementation of a manure nutrient management plan and application setbacks along in-field drainage channels would reduce water quality parameter concentrations in runoff at this site.
  - It was expected that dissolved forms of nutrients would be reduced more than particulate forms.

4.9.2 Methods

4.9.2.1 Site Description and Management

The SFD site was a quarter-section field in the southern part of the sub-watershed (Figure 4.3). The size of the field was 63 ha, but only 51 ha were included in the BMP site. Drainage at the site consisted of two shallow channels entering from the west and converging into a single channel in the northeast (Figure 4.56).

The northwest half of the SFD quarter section was in the same AGRASID soil landform model (CYLP1/U1h) as described for the WFD site (Alberta Soil Information Centre 2013) (Sub-section 4.6.2.1). The southeast half of the SFD quarter section was in the same AGRASID soil landform model (CYLP2/U1hc) as described for a portion of the NFD site (Sub-section 4.7.2.1). The surface soil at the site had a loam texture (35% sand, 19% clay), pH of 6.2, electrical conductivity of 0.7 dS m^{-1}, 3110 mg kg^{-1} TN, 796 mg kg^{-1} TP, and 7.4% organic matter (Appendix 4).

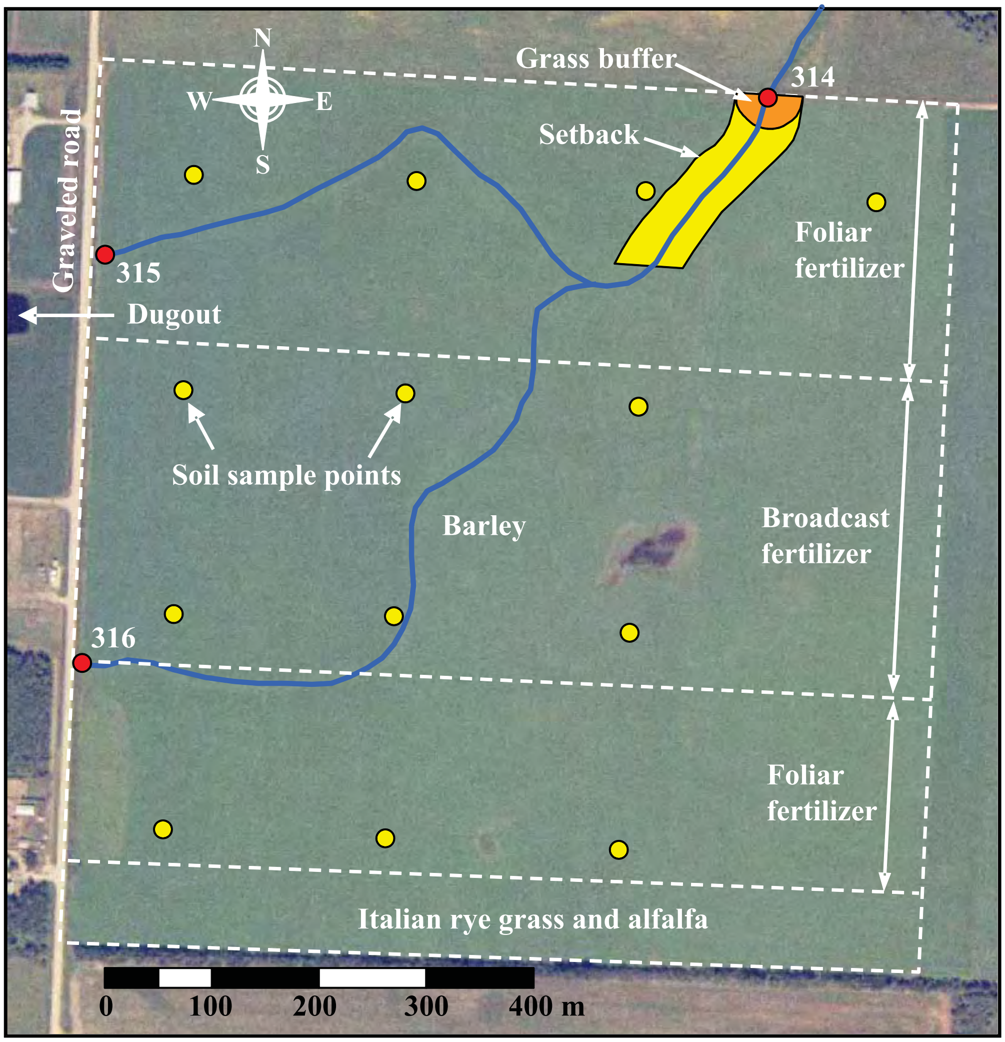

Figure 4.56. The South Field site showing the location of the three water monitoring stations (Stations 314, 315, and 316), soil sampling points, the 30-m setback along a portion of the main drainage channel, the grass buffer zone near Station 314, fertilized areas in 2010, and crop types used in 2010.

The SFD site was mainly under annual crop production during the study. Crops grown on this field included canola, barley, corn, and alfalfa. The entire field was seeded to canola in 2007, as was a 6-ha parcel along the east side of the field in 2008 and 2009 (Table 4.55). Barley was grown on most of the field (57 ha) from 2008 to 2010. In 2011, corn silage was grown on the south part of the field and canola was grown on the north part of the field. In 2012, corn silage was grown on the east part of the field and barley was grown on the west part of the field. From 2010 to 2012, a 6-ha strip along the south end of the field was planted to Italian rye grass and alfalfa. All seeding was completed in May of each year (Table 4.55). Most seeding was followed with harrows and rollers to cover the seed. Given the small size of the drainage channels in the field, the channels were often farmed through and seeded.

Herbicides were applied typically in mid-June for weed control and in September to desiccate the barley crop before harvest. Harvest occurred in mid-September to mid-October, and straw was baled and removed for the canola and barley crops (Table 4.56). After harvest, the field was typically not tilled, except in 2010.

Prior to seeding in the spring, liquid dairy manure was surface applied on the whole field at rates ranging from 45 to 66.7 Mg ha^{-1} and then incorporated (Table 4.57). The SFD was owned by the same dairy producer as the EFD field (Section 4.8.2.1) and the source of manure was from the same lagoon. Inorganic fertilizer was also applied just prior to or during seeding, or as a foliar application in June 2008 to 2010.

Table 4.55. Seeding and fertilizing details at the South Field from 2007 to 2012.[z]

				Fertilizer					
	Area		Seeding	N	P	K	S	Cu	
Year	(ha)	Crop	date	--------------------	--------------------	(kg ha^{-1})	--------------------	--------------------	Tillage[y]
				Pre BMP					
2007	63	canola	May 22	na[x]	na	na	na	na	H,R
2008[w,v]	57	barley	May 27-28	0.4	1.3	0.4	-	-	na
2009[u,t]	57	barley	May 16,19	na	na	na	na	na	H,R
				Post BMP					
2010[s,r]	57	barley	May 21-22	122	-	14	9	2	R
				0.3	0.4	0.25	-	-	
2011[q]	42	corn	May 14	-	-	-	-	-	R
	15	canola[p]	May 19	32	na	na	na[p]	na	R[o]
2012[n,m]	17	corn	May 12	101	-	-	-	-	R
	40	barley	May 21	101	-	22	-	-	R

[z] Not all dates are exact.
[y] H = harrows, and R = rollers.
[x] na = not available.
[w] 6 ha of canola planted on the east side. Boron, Yieldmax®, and Proline® foliar was applied on July 10. Canola yielded 3.08 Mg ha^{-1} in early October 2008.
[v] Foliar application of 7.4 kg ha^{-1} of 6-18-6 on June 20.
[u] 6 ha of canola seeded on the east side. Roundup® was sprayed on May 11, 2009.
[t] Foliar application at unknown rate of 6-18-6 with unknown herbicide were applied on June 16 and 17.
[s] A small, 5.7-ha strip along the south edge of the field was seeded to Italian rye grass and under seeded with alfalfa. The first cut of the rye grass consisted mostly of weeds; whereas, a second cut in mid-August yielded 1.24 Mg ha^{-1} (wet weight). For 2011 and 2012 management data, refer to EFD data (Section 4.8.2.1).
[r] Broadcast application of 193.9 kg ha^{-1} of 63-0-9-4.8-1 was applied on May 17 on the central portion of the field. Foliar application of 4.94 kg ha^{-1} of 6-18-6 was applied on June 15 on the remaining north and south sections of the barley crop.
[q] Corn was seeded on the south portion of the field and canola was seeded on the north portion.
[p] 31.8 kg ha^{-1} of N and a bit of S with canola at a seeding rate of 5.4 kg ha^{-1}.
[o] Only half of the canola was rolled.
[n] 17 ha on east side of field were seeded to corn and 40 ha on west side were seeded to barley.
[m] 100.9 kg ha^{-1} of N applied May 15 with the corn and May 21 with the barley. 22.4 kg ha^{-1} of K also applied with the barley.

Table 4.56. Herbicide and harvest management information for the South Field from 2007 to 2012.[z]

Year	Crop	Herbicide date(s)	Pre-harvest method	Pre-harvest date	Harvest date	Yield (Mg ha^{-1})	Straw harvested
			Pre BMP				
2007	canola	June 15	swathed	Sep 15	Oct 15	2.80	yes
2008	barley	-	na[y]	na	Sep 15-22	4.84-5.11	yes
2009	barley	June 16-17	desiccated	Sep 03	Sep 6-12	3.77	na
			Post BMP				
2010	barley	June 15	desiccated	Sep 20	Oct 4,10	4.43	yes
2011	corn	June 11	-	-	Oct 17-18	38.3	-
	canola	June 11	swathed	Sep 10	Oct 7	2.47	yes
2012	corn	June 5	-	-	Oct 17-18	53.1	-
		June 26					
	barley	June 15	desiccated	Aug 28	Sep 13	4.61	yes

[z] Not all dates are exact.
[y] na = not available.

Table 4.57. Liquid manure management details at the South Field from 2007 to 2012.[z]

Year	Manure application date	Manure application rate (Mg ha^{-1})	Incorporation Date	Incorporation Type	Incorporation Depth (cm)	Incorporation Days after application
			Pre BMP			
2007	May 1	61.78	May 2	disc	10	1
			May 20[y]			
2008	May 14-26[x]	61.78	May 27-28	disc	na	1-14
2009	Apr 20-24	45	May 11	disc	10	17-21
			Post BMP			
2010	Apr 12-19	47.9	Apr 15-22[w]	disc	10	3
2011	May 10-12	66.72	May 13	cultivator	12.5	1
			May 14	disc	12.5	
2012[v]	May 9-10	66.72	May 10	cultivator	12.5	1
			May 11	disc	12.5	

[z] Not all dates are exact.
[y] Followed by two passes of harrows on May 21.
[x] Application was started on May 14, was stopped then finished by May 26.
[w] Followed by harrows from May 11-13 at 5-cm depth.
[v] Some liquid manure spread on southeast corner and one pass along the west side of field on April 30. An additional unknown amount of solid manure was spread on southeast corner during application of liquid manure.

4.9.2.2 Implementation of Beneficial Management Practices

The BMPs were implemented in spring 2010 and were continued in 2011 and 2012. The BMP plan included switching from surface applied to injected liquid manure, using nutrient management plans to determine manure application rates, using manure application setbacks along the drainage channel, and establishing a permanent vegetative buffer at the outlet of the drainage channel. Unfortunately, the injection of liquid manure was not achieved during this study because injection equipment was not available at the times when the producer was ready to apply manure in the spring.

Nutrient management plans were developed based on soil samples collected in fall 2009 to 2011 (Sub-section 4.9.2.3) and manure samples collected from 2008 to 2011 (Sub-section 4.9.2.4). The SFD and EFD sites were owned by the same producer and liquid manure came from the same lagoon for both sites. Manure samples were collected in 2007, 2009, and 2011 for the EFD site, and the results from these samples were also used for the SFD nutrient management plan. Based on meeting one-year of N requirement for the crops, the AFFIRM program (AAFRD 2005b) recommended application rates of 67, 90, 145, 106 kg ha^{-1} N for the assumed crops of wheat in 2010, corn silage and canola in 2011, and barley silage in 2012, respectively, under medium (2010) or wet (2011 and 2012) soil moisture conditions. No P application was recommended. Note that barley was grown in 2010 instead of wheat (Table 4.55). These recommended N rates were adjusted downward to allow for residual carryover from manure applied in the previous 2 yr. For example, it was estimated that manure applied in 2008 and 2009 provided 10.6 kg ha^{-1} N in the 2010 crop year. Therefore, the required N for 2010 was reduced from 67 to 56.4 kg ha^{-1}. To provide the required amounts of crop available N from manure, application rates were calculated at 43.4 Mg ha^{-1} for 2010, 57.2 (corn silage) and 101 Mg ha^{-1} (canola) for 2011, and 66 Mg ha^{-1} for 2012. Manure application rates were calculated assuming 25% of organic N (TN less NH_4-N) was mineralized during the crop year, 50% of the NH_4-N was lost as ammonia after application, and nutrient content of manure was an average of the analytical results of manure samples collected prior to a given crop year. The actual application rates of liquid manure were 48 Mg ha^{-1} in 2010 and 67 Mg ha^{-1} in 2011 and 2012 (Table 4.57). Additional solid manure, of an unknown amount, was applied to the southeast corner of the field at the time of liquid manure application in 2012.

For manure application in 2010 to 2012, a setback distance of 30 m from the drainage channel was used where manure was not applied. The setback distance was based on the regulations in the Agricultural Operation Practices Act (AOPA) (Province of Alberta 2010). The manure setback was implemented along a defined portion of the drainage channel, extending 190 m upstream from edge-of-field Station 314 (Figure 4.56).

A grass buffer was seeded in a 30-m wide, semi-circle area at the drainage channel outlet and immediately upstream from Station 314 (Figure 4.56) on May 25, 2010. The 0.14-ha area was seeded with a grass mix of 35% orchardgrass (*Dactylis glomerata*), 25% timothy (*Phleum pratense*), 20% creeping red fescue (*Festuca rubra*), 10% alsike clover (*Trifolium hybridum*), and 10% reed canary grass (*Phalaris arundinacea*). The seeding rate was 15.6 kg ha^{-1}. This mixture was chosen because of its tolerance to moist soil. The seed mixture was broadcasted with a push-type spreader and the area rolled the next day. The small area seeded to the grass mixture had already been seeded to barley a few days prior. The grass failed to establish because of sparse germination, and as a result, the area was cultivated in fall 2010. The grass buffer was re-seeded on May 27, 2011. This time the area was 15 m wide and seeding rate was 192.8 kg ha^{-1}. The buffer failed to establish due to heavy summer runoff eroding the area. A third attempt was tried in fall 2011 when the site was re-seeded (128.9 kg ha^{-1}) on September 20. However, germination continued to be poor due to dry soil conditions. Another seeding of the buffer was carried out in spring 2012 to fill in the bare spots, but was mistakenly cultivated during manure incorporation. No further attempts were made to establish a grass buffer at this site.

4.9.2.3 Soil Sampling

Soil characterization samples (Sub-section 2.9) were collected on October 21, 2009. Agronomic 0- to 15-cm samples were collected at 13 sampling points annually (2007 to 2012) (Figure 4.56). Other soil samples included 0- to 60-cm soil-test samples in the fall (2009 to 2011), and pre- and post-seeding samples (2011). The analysis of soil samples is described in Sub-section 2.9.6.

Soil-test samples for the project were generally sampled using transects based on field topography (Sub-section 2.9). In 2010, however, because of time constraints, the samples were collected in conjunction with the agronomic samples using the 200-m grid (Figure 4.56). It was assumed that the grid would provide representative samples that were comparable to the transect method as the field was relatively flat.

Pre- and post-seeding samples were collected to determine the difference in soil nutrient concentrations before and after the application of manure. The samples were collected with a Dutch auger from 0 to 15 cm using the agronomic 200-m grid on May 5, 2011 (i.e., pre-seeding). Data from the regular annual agronomic samples were used to represent the post-seeding nutrient concentrations as sampling methodology was the same (Sub-section 2.9). The post-seeding samples were collected on June 2, 2011.

4.9.2.4 Manure Sampling

Liquid dairy manure samples were collected each spring from 2008 to 2012. Samples were collected from the loading spout at the lagoon while the manure spreader was filled. Samples were collected on two dates in 2008 (May 6 and 14) and in 2010 (April 13 and 15), and the results from the two dates for each year were averaged. Samples were analyzed for water and nutrient content (Sub-section 2.10).

4.9.2.5 Water Flow and Quality

This site was instrumented with three water monitoring stations. Stations 315 and 316 were located upstream at two entry points to the field, and Station 314 was located downstream at the exit point (Figure 4.56). All three stations were equipped with circular flumes and Isco automated water samplers (Sub-sections 2.6, 2.7, and 2.8). The flumes at Stations 315 and 316 were physically lowered in summer 2009 because of water pooled in front of the flumes and soil eroded under the wooden wingwalls. There was no flow connectivity between the two upstream stations (315 and 316) and Station 314 from 2008 to 2010. Because of this, the pre-BMP (2008 to April 2010) versus post-BMP (May 2010 to 2012) data from Station 314 were only used in the statistical comparisons between the two BMP periods. Therefore, Station 314 was treated as an edge-of-field station. Statistical comparisons were only completed for snowmelt, as only one pre-BMP rainfall sample was collected at Station 314.

The post-BMP period began with the application of manure in April 2010. Water samples collected before May 2010 were in the pre-BMP period and samples collected after April 2010 were in the post-BMP period. Statistical analyses and load calculations are described in Sub-section 2.8.4.

4.9.3 Results and Discussion

4.9.3.1 Implementation of Beneficial Management Practices

The implementation of the BMP plan was partially successful and this included the use of 30-m setbacks and the nutrient management plan. Components of the plan not successfully implemented included the switch to injected manure application and the establishment of a grass buffer area. Plus, the manure application rates used slightly exceeded recommended values.

As described above, the setbacks were only applied for a short distance (190 m) upstream from Station 314 (Figure 4.56). Because the field was relatively flat and connective flow often did not occur, it was felt that setbacks were not required for the entire length of the field channels at this site. This offered a practical balance between using setbacks and minimizing the inconvenience of setbacks when applying manure to the field.

The actual manure application rates were similar to the calculated rates in the nutrient management plan in 2010 and 2012 (Table 4.58). In 2011, the amount of manure was over applied for corn and under applied for canola relative to the calculated rates. Even though the manure rates were determined to meet the crop N requirement, the producer still applied commercial N fertilizer. In 2010, 122 kg ha^{-1} fertilizer N was applied to a portion of the field and it was estimated that nearly 140 kg ha^{-1} of excess N was applied (Table 4.58). For the areas of the field not applied with fertilizer in 2010, the over application of N was estimated at only about 17 kg ha^{-1}. Over application of N was also estimated for the corn crop in 2011 and the barley crop in 2012. The former was caused by a higher than expected manure application rate and the latter was cause mainly by the application of 101 kg ha^{-1} N fertilizer. In contrast, even though manure was under applied for the canola crop in 2011, the application of 32 kg ha^{-1} of fertilizer N supplemented the shortfall without causing an over application of N.

The amount of TP added with the manure applications was 36 kg ha^{-1} in 2010, 42 kg ha^{-1} in 2011, and 43 kg ha^{-1} in 2012. Based on TP removal values from the Canadian Fertilizer Institute (2001) and crop yields from SFD (Table 4.55), the amount of TP removed from the SFD site ranged from 17 to 51 kg ha^{-1} from 2010 to 2012. Except for the corn silage in 2012, it was estimated that the application of manure resulted in a minor accumulation of TP in soil ranging from 5 to 26 kg ha^{-1} yr^{-1}.

Manure nutrient management plans are based on several assumptions that could result in the under or over application of nutrients. The nutrient content of manure was based on previous manure samples and not on the nutrient content of the applied manure, and this could account for some discrepancies. Also, when a nutrient management plan was developed for the next crop season the crop type and potential yield were assumed. The crop yield in 2010 was the same as used in the AFFIRM program; whereas, corn yields in 2011 and 2012 were much higher than used in AFFIRM. The corn crops, therefore, would have removed more nutrients than was predicted. The canola yield in 2011 was slightly less than predicted and therefore removed fewer nutrients than predicted. Regular soil testing is recommended to monitor STP and other nutrients.

Two aspects of the BMP plan that were not successful included switching to manure injection and establishing a buffer zone. Manure application at this site typically occurred in the spring, which is a better practice than applying manure in the fall. Spring application avoids the spring

Table 4.58. Recommended nitrogen (N) compared to estimated available N applied from 2010 to 2012 at the South Field.

Year	Crop	Recommended N^z (kg ha^{-1})	Calculated manure rate (Mg ha^{-1})	Manure applied (Mg ha^{-1})	Available N in applied manure[y] (kg ha^{-1})	Commercial fertilizer N applied (kg ha^{-1})	N difference[x] (kg ha^{-1})
2010	barely	56	43	48	73	122 / 0.3[w]	+139 / +17.3
2011	corn	73	57	67	95	0	+22
	canola	128	101	67	95	32	-1
2012	barley	86	66	67	93	101	+108
	corn	nd[v]	nd	67	93	101	-

[z] Amount recommended by AFFIRM less the estimated residual N from the previous 2 yr of manure application.
[y] Available N from the applied manure in a given year was based on the actual nutrient content of the manure applied and assuming a 50% loss of NH_4-N and a mineralization rate of 25% of organic N (TN - NH_4-N).
[x] Difference between recommended and applied N (manure plus fertilizer). A positive value indicates more than the recommend amount was applied.
[w] See Table 4.55.
[v] nd = not determined.

snowmelt period. However, at this site, liquid manure was first broadcasted and then incorporated by tillage. Injecting liquid manure is considered a better practice because manure is placed below the soil surface and less exposed to surface runoff, the loss of N by ammonia volatilization is reduced and more N is retained in the soil for crop use, and odour is reduced. The landowner of the SFD site did not own liquid manure injection equipment. Attempts were made to hire a custom applicator, but because of poor timing and the fact that applying manure to the SFD was a relatively small job for a contractor, we were not able to implement this component of the BMP plan. Part of the timing issue was related to spring conditions when the period of opportunity to apply manure (i.e., after snowmelt and before seeding) is much shorter compared to late summer and fall.

The establishment of a small grass buffer at the drainage outlet of the field in 2010 was not successful because of poor germination of the seed. Three more attempts were made in 2011 and 2012 to establish a grass buffer area, but in all attempts, grass did not establish for various reasons including too much water in spring 2011 (Figure 4.57). As a result, this component of the BMP plan was abandoned. Better success may have occurred if different equipment and methodology had been used, rather than broadcasting the seed on the surface and raking by hand. However, because of the small area and location, options were limited.

It was decided not to establish a grass cover along the entire drainage channel in the field because the field was relatively flat and there was often non-connective flow. Converting all of the drainage channels to grassed waterways would have resulted in 8.5 ha of land loss to the producer with likely minimal environmental benefits. As indicated above, in many years, the channels were dry enough to be cropped.

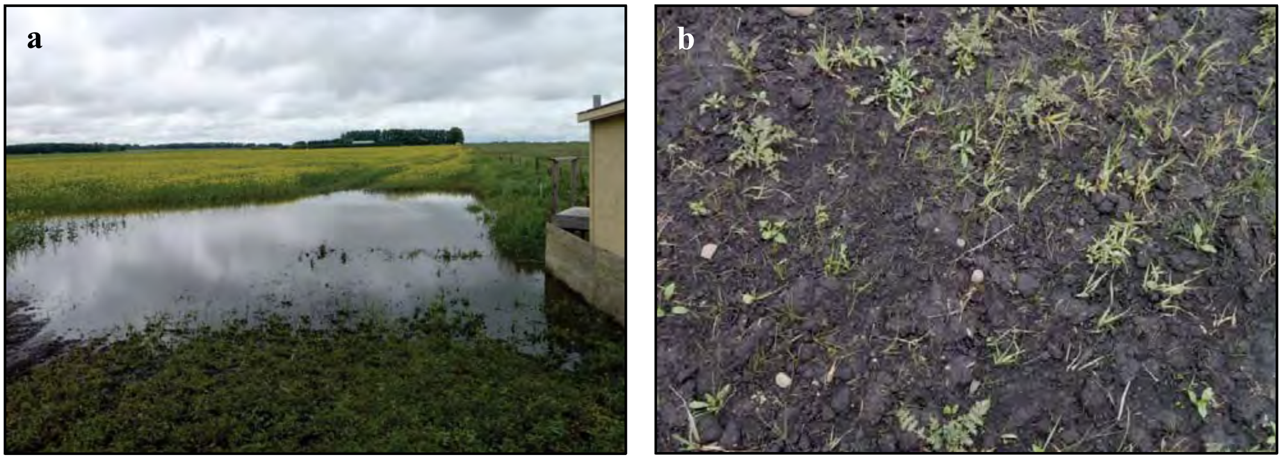

Figure 4.57. The 15-m grass buffer at Station 314 showing poor germination on July 12, 2011.

Costs for BMP implementation from 2010 to 2012 included the cost of soil and manure sampling and analysis, flagging the 30-m manure setback area, producing a nutrient management plan, and seeding the grass buffer (Table 4.59).

4.9.3.2 Soil

Agronomic samples. Extractable NO_3-N concentration was higher in the spring than the fall during the study (Table 4.60). The spring values represent soil conditions after manure and fertilizer application and the reductions each fall was likely caused by crop uptake and removal. For the four years (2008 to 2011) for which spring and fall samples were collected, the NO_3-N concentration was 2.5-folder higher compared to the fall on average. Extractable NH_4-N fluctuated slightly with time, but remained relatively consistent. The concentration of STP also fluctuated with time and showed no strong trend. The average spring concentration of STP was 65 mg kg^{-1} compared to 76 mg kg^{-1} in the fall. The average STP concentration was only slightly above the agronomic threshold of 60 mg kg^{-1} (Howard 2006) and was not considered excessive in terms of P accumulation in the soil.

Table 4.59. Cost of beneficial management practices at the South Field from 2010 to 2012.

Item	Cost ($)	Labour (h)
Soil sampling[z]	308.25	12
Manure sampling[y]	776.25	6
Manure setback (x3)	-	6
Nutrient management plan (x3)	-	3
Grass buffer (x4)	180.00	6
Total	**1264.50**	**33**

[z] Three samples (0-15, 15-30, 30-60 cm) were submitted each fall from 2009 to 2011 and the cost of analysis was $34.25 per sample.
[y] Four, three, and two samples were submitted in spring 2010 to 2012, respectively, and the cost of analysis was $86.25 per sample.

Table 4.60. Average concentrations for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for the agronomic soil samples (0 to 15 cm) collected from 2007 to 2012 at the South Field.

	NO_3-N		NH_4-N		STP	
	Spring	Fall	Spring	Fall	Spring	Fall
Year	(mg kg^{-1})					
2007	ns[z]	7	ns	6.4	ns	66
2008	31	18	3.9	4.4	70	78
2009	25	6	4.8	4.6	65	66
2010	28	18	8.5	4.8	53	79
2011	32	12	5.1	3.9	73	90
2012	33	ns	7.7	ns	61	ns

[z] ns = not sampled.

Soil-test samples. Extractable NO_3-N, NH_4-N, and STP were similar in that the highest concentrations were in the top 0- to 15-cm of soil and then decreased with depth (Table 4.61). The NO_3-N concentrations in the 0- to 60-cm soil layer were low in terms of meeting crop requirements, and the nutrient management plans determined that added N was required for optimum crop growth (Table 4.58). In contrast, STP in the 0- to 15-cm soil layer was above the agronomic threshold of 60 mg kg^{-1}, and as a result, no addition of P was recommended at this site for the crop years from 2010 to 2012 (Sub-section 4.9.2.2).

Pre- and post-seeding samples. The average concentrations of NO_3-N, NH_4-N, and STP were higher in the post-seeding samples compared to the pre-seeded samples; however, the differences were not statically significant ($P < 0.1$; Table 4.62), even though NO_3-N seem to have increased by nearly three-fold. Liquid dairy manure was applied from May 10 to 12 at a rate of 67 Mg ha^{-1}, and commercial N fertilizer was applied on May 19 to the canola portion of the field at a rate of 32 kg ha^{-1}. The area seeded to canola in 2011 included the four soil sampling points along the north end of the field (Figure 4.56). The apparent increase from 11 to 32 mg kg^{-1} NO_3-N could be accounted for by the N in the manure. Assuming nutrients remained in the top 15-cm soil layer after application and before the post-seeding sampling and a soil bulk density of 1.2 g cm^{-3}, the amount of NH_4-N in the manure (Sub-section 4.9.3.3) could more than account for the increase in NO_3-N concentration. Typically, liquid manure has very low concentration NO_3-N. However, when NH_4-N in manure is added to soil, the NH_4-N is converted to NO_3-N within a short period of time. This seemed to have been the case at the SFD site in spring 2011, as soil extractable NH_4-N increased by only a small amount (Table 4.62). As well, some of the organic N in the manure may have mineralized providing additional NO_3-N. Similarly, the amount of STP increased from pre- to post-seeding and was less than the TP added in the manure. Therefore, the amount of P added in manure could have accounted for the increase in STP. However, only a portion of the TP in the manure would have been in available form and measured as part of the STP in the post-seeding samples. The available form of P (i.e., orthophosphate) was not measured in manure during this study. In a field study in Alberta, Olson and Papworth (2006) reported that the portion of TP in the form of orthophosphate ranged from 16 to 46% for solid cattle and liquid hog manures.

Table 4.61. Soil-test results for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for the South Field in fall 2009 to 2011.

Soil layer (cm)	NO_3-N	NH_4-N	STP
	------------	(mg kg^{-1})	------------
	2009		
0 to 15	9	5.7	72
15 to 30	2	4.4	17
30 to 60	1	4.0	11
	2010		
0 to 15	13	3.2	73
15 to 30	7	2.1	7
30 to 60	3	2.8	4
	2011		
0 to 15	4	2.6	64
15 to 30	1	1.6	12
30 to 60	1	1.6	6

Table 4.62. Average nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) values for pre- and post-seeding soil samples collected at the West Field in 2011.

	NO_3-N[z]	NH_4-N[z]	STP[z]
		($mg\ kg^{-1}$)	
Pre-seeding[y]	11	3	64
Post-seeding[x]	32	5	73

[z] Averages between pre- and post-seeding were not significantly different at P <0.1.
[y] Pre-seeding samples were collected May 5, 2011.
[x] Post-seeding samples were collected June 2, 2011.

4.9.3.3 Manure

The liquid dairy manure contained 93% water on average, with annual averages that ranged from 91 to 97% (Table 4.63). Average TN concentration was within the concentration range in the Manure Characteristics and Land Base Code (AFRD 2006) used for AOPA (Province of Alberta 2010). Total P and K concentrations were about two-thirds of the values reported by AFRD (2000).

4.9.3.4 Water Flow and Quality

Water flow. Annual flows varied widely among the three monitoring stations and among years. No flow occurred at Station 315 in 2008 and at Station 316 in 2009 (Table 4.64). The lowest annual flow at Station 314 was in 2009. The highest annual flow at all three stations was in 2011, and the annual flows in 2011 were much larger compared to 2008 to 2010. Flow at the stations from 2008 to 2010 was less than 4% of the flow in 2011. The second highest annual flows occurred in 2012, and these flows were 17 to 26% of the flows in 2011. At Station 314, most of the flow occurred in March and April from 2008 to 2010, from March to August in 2011, and from March to June in 2012 (Figure 4.58).

Table 4.63. Average water and nutrient content in liquid dairy manure applied to the South Field.[z]

Sampling date	Number of samples	Water (%)	NH_4-N	Total N	Total P	Total K	Total S	Total Na
					($kg\ Mg^{-1}$)			
May 2008[y]	6	97	2.38	2.98	0.35	1.97	0.20	0.48
Apr 29, 2009	3	92	1.93	3.29	0.64	2.81	0.36	0.46
Apr 2010[x]	4	91	2.00	4.08	0.75	3.26	0.45	0.44
May 12, 2011	3	93	2.09	3.63	0.63	3.09	0.37	0.37
May 10, 2012	2	92	1.84	3.71	0.64	2.77	0.39	0.35
Overall Average	18	93	2.11	3.47	0.56	2.67	0.33	0.44

[z] Values are expressed on a wet-weight basis.
[y] Samples were collected on May 6 and 14. Three samples were collected on each date.
[x] Samples were collected on April 13 and 15. Two samples were collected on each date.

Table 4.64. Annual flow and proportions attributed to snowmelt and rainfall runoff at the upstream Stations 315 and 316 and downstream Station 314 at the South Field from 2008 to 2012.

	Annual flow			Proportion as snowmelt			Proportion as rainfall		
	315	316	314	315	316	314	315	316	314
Year	-------- (m^3 yr^{-1}) --------			---------- (%) ----------			---------- (%) ----------		
2008 (pre-BMP)	11	0	3,416	100	0	99	0	0	1
2009 (pre-BMP)	0	1,844	1,148	0	100	100	0	0	0
2010 (pre- & post-BMP)	102	935	4,814	0	0	99.6	100	100	0.4
2011 (post-BMP)	181,045	50,811	257,087	40	30	45	60	70	55
2012 (post-BMP)	34,196	12,992	43,712	52	80	80	48	20	20

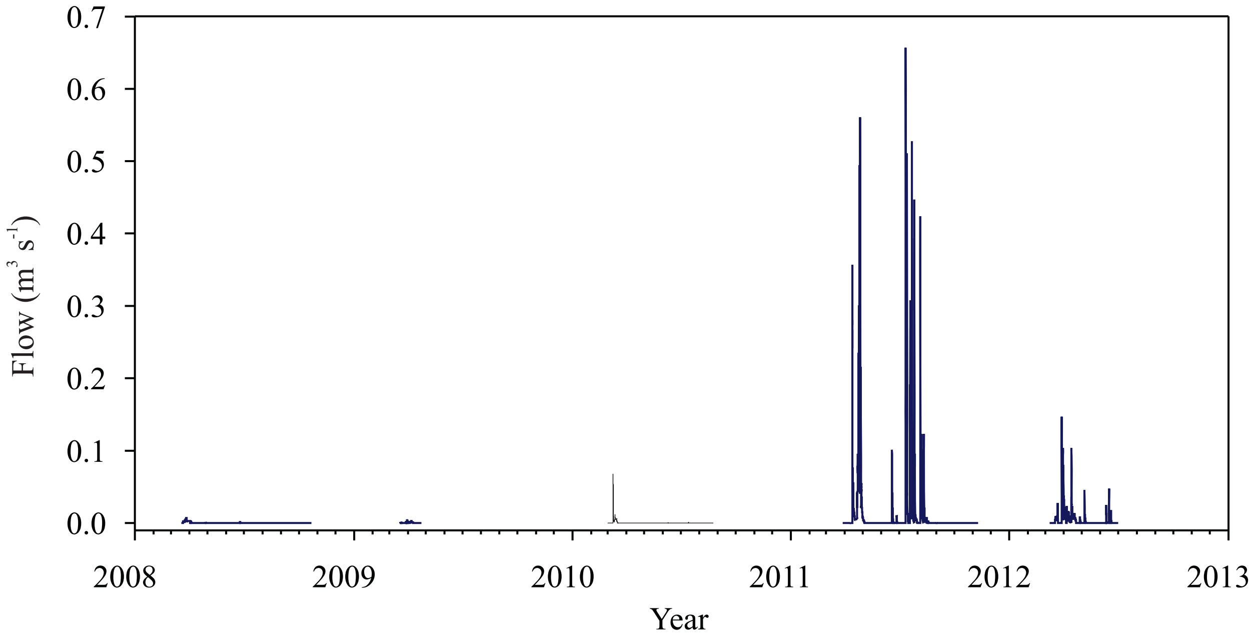

Figure 4.58. Hydrograph for the downstream Station 314 at the South Field from 2008 to 2012.

Snowmelt generated most of the surface flow at the two upstream stations in 2008, 2009, and 2012. In contrast, rainfall runoff was the major contributor in 2010 and 2011 at these stations (Table 4.64). The proportion of flow at Station 314 caused by snowmelt ranged from 45 to 100% among the years, with an average of 85%. The measurement of flow caused by snowmelt at Station 314 may be inaccurate in 2010 as freeze-thaw conditions (Figure 4.59a,b) and pooling in front of and behind the flume (Figure 4.59c,d) affected measurements. The pooling of water was exacerbated by the low slope and buildup of snow and ice in the drainage channel downstream from the flume; however, attempts were made to collect water samples during active flow when pooling was minimal. Similar difficulties in measuring flow during snowmelt were experienced at other monitoring stations in the WHC Sub-watershed in 2010.

Figure 4.59. Images showing (a) snowmelt runoff water pooled upstream from Station 314 on March 9, 2010, (b) snow in drainage channel downstream from Station 314 on March 9, 2010, (c) runoff water frozen in the field upstream from Station 314 on March 10, 2010, and (d) frozen water at the exit of the flume at Station 314 on March 10, 2010.

Even though the purpose of Stations 315 and 316 was to monitor water entering the field and potentially contribute to flow at the downstream Station 314, very little connective flow occurred between the two upstream stations and Station 314, particularly in 2008 to 2010. Very little flow or no flow occurred at Stations 315 and 316 in 2008 and 2010 compared to Station 314, suggesting that all of the flow at Station 314 originated from within the field. In 2009, the annual flow at Station 316 was actually larger than at Station 314. However, most (>70%) of the flow at Station 314 occurred prior to April 6 when flow began at Station 316 (data not shown). In addition, field observations confirmed that water from Station 316 did not reach Station 314 in 2009. Field observations in 2008 and 2010 also confirmed the lack of connective flow. Plus there was pooled water at the two upstream stations prior to physically lowering the flumes in summer 2009. Because there was no connective flow along the drainage channels from 2008 to April 2010, which was the pre-BMP period, Station 314 functioned as an edge-of-field station with runoff originating from within the field. Because of this, water quality data from Station 314 only were used to evaluate the effectiveness of the BMPs at this site.

The annual flows were much higher in 2011 and 2012 (Table 4.64). The combined annual flows at Stations 315 and 316 were 90% and 108% of the annual flow at Station 314 in 2011 and 2012, respectively. In 2011 and 2012, there was some flow connectivity, particularly during rainfall runoff. It could not be confirmed how many of the sampling days in 2011 and 2012 had connective flow, and it was assumed that most of the water that flowed through Station 314 originated from the field.

Along the west side of the SFD site was a graveled road (Figure 4.56). Most of the water that flowed at Stations 315 and 316 and into the field originated from drainage areas west of the graveled road. The sizes of the drainage areas were about 296 ha for Station 315 and 17 ha for Station 316. The size difference between the two drainage areas reflected the difference in annual flows in the two high flow years (2011 and 2012), with about three-fold greater annual flows at Station 315 compared to Station 316 (Table 4.64). Water from these drainage areas flowed through road culverts, with two culverts by Station 315 and one culvert by Station 316 (Figure 4.60). On the west side of the road, across from Station 315, was a dugout (Figure 4.60b), which received water from a drainage channel to the southwest. In high flow years, the dugout overflowed, entered the road ditch, and flowed through the culvert and towards Station 315. For Station 316, water collected along the west road ditch and entered the culvert (Figure 4.60d). In comparison, the drainage area between the two upstream stations and Station 314 (i.e., the cropped field) was about 49 ha in size. As indicated previously, most of the flow originated from within the field and little water from Stations 315 and 316 reached the downstream station.

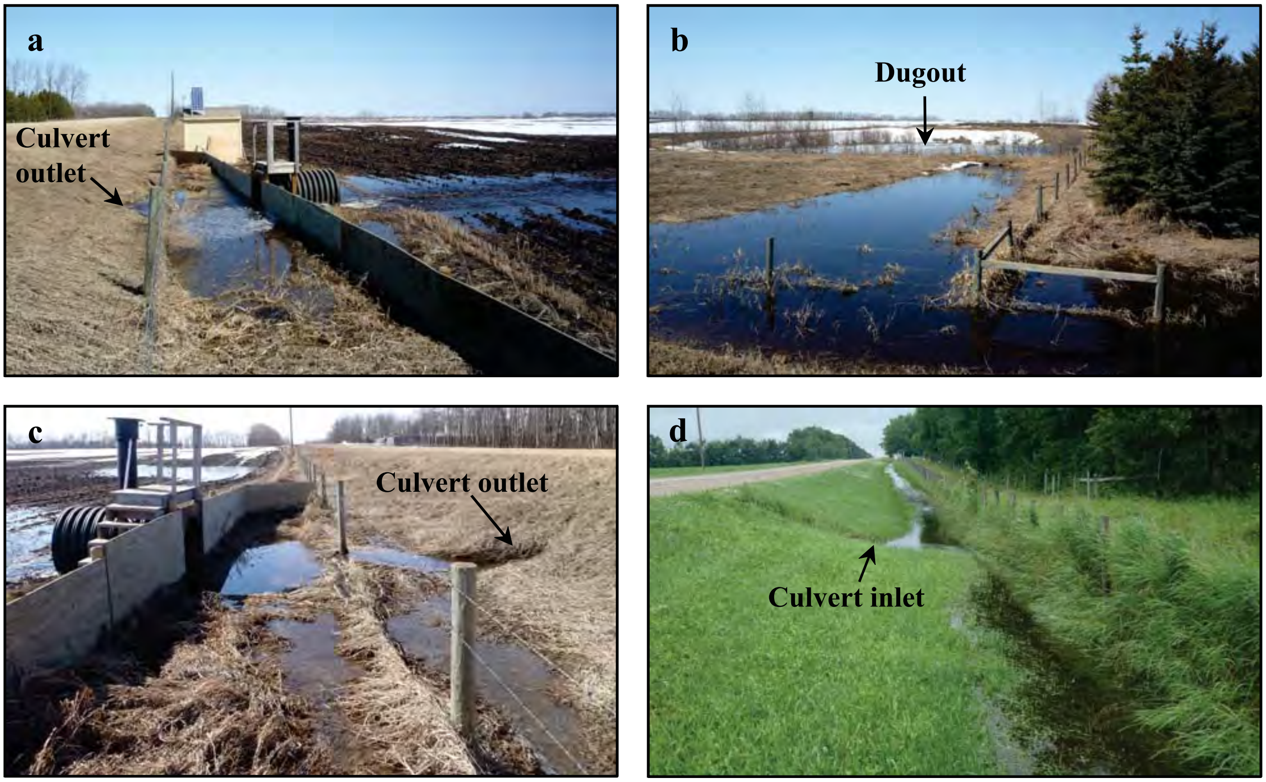

Figure 4.60. Upstream monitoring stations at the South Field showing (a) Station 15 (north view) on April 24, 2011, (b) dugout and overflowed water on the west side of the road from Station 315 on April 24, 2011, (c) Station 316 (south view) on April 25, 2011, and (d) west road ditch and culvert inlet (south view) immediately across the road from Station 316 on July 22, 2011.

General water quality observations. Nearly all of the samples from Station 315 and about 82% of the samples from Station 316 were collected in 2011 and 2012 (Table 4.65). Therefore, the water quality results from Stations 315 and 316 essentially represented these two years.

Generally, the average concentrations of N and P parameters were higher during snowmelt runoff compared to rainfall runoff at Stations 315 and 316 (Table 4.65). For example, TN was 90% higher and TP was 39% higher in snowmelt runoff at Station 315. One exception was for ON at Station 316, which had similar concentrations of ON between snowmelt and rainfall runoff. In contrast, the average concentrations for Cl, TSS, *E. coli*, and EC were for the most part lower during snowmelt compared to rainfall runoff. However, the opposite was true for TSS at Station 316. The average values for pH was similar between snowmelt and rainfall. The largest difference between snowmelt and rainfall runoff was for *E. coli*, which was expected as microbial activity is very low during the colder conditions of snowmelt compared to rainfall conditions.

Table 4.65. Average concentration of water quality parameters at Stations 315, 316, and 314 at the South Field from 2008 to 2012.[z]

Year (n)[y]	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli* (mpn 100 mL^{-1})	EC ($\mu S\ cm^{-1}$)	pH
	($mg\ L^{-1}$)											
Station 315 (snowmelt)[x]												
2011 (15)	8.40	2.25	5.99	0.09	0.92	0.85	0.07	20	12.6	2	327	7.78
2012 (13)	11.9	2.83	8.87	0.22	0.65	0.52	0.12	9	36.1	22	543	7.88
All (28)	10.0	2.52	7.33	0.15	0.79	0.70	0.10	15	23.5	11	428	7.82
Station 316 (snowmelt)[x]												
2008 (6)	10.1	5.30	3.31	1.37	6.81	6.15	0.66	70	na[w]	9	519	7.58
2009 (3)	12.9	7.09	4.65	1.11	6.05	5.68	0.37	9	26.4	87	389	7.81
2011 (17)	7.23	2.56	4.35	0.27	2.68	2.63	0.06	7	17.1	2	379	7.72
2012 (11)	13.4	3.05	9.97	0.32	1.36	1.30	0.06	8	49.8	8	603	7.86
All (37)	9.98	3.52	5.88	0.53	3.23	3.05	0.18	18	29.6	12	469	7.75
Station 314 (snowmelt)[v]												
2008 (13)	4.94	3.37	0.43	1.04	1.62	1.38	0.22	22	na	8	290	7.42
2009 (13)	3.79	2.42	0.95	0.38	1.25	1.13	0.12	16	4.63	4	105	7.32
2010 (9)	3.68	2.84	0.63	0.16	2.87	2.66	0.22	12	7.81	154	159	7.22
2011 (21)	12.7	2.94	9.50	0.17	2.26	1.53	0.72	256	15.4	2	298	7.46
2012 (19)	9.79	3.77	5.15	0.78	2.26	1.98	0.28	54	28.8	49	492	7.64
All (75)	7.99	3.12	4.28	0.51	2.05	1.69	0.36	94	16.1	35	296	7.45
Station 315 (rainfall)[x]												
2010 (1)[y]	1.30	1.14	0.11	0.03	0.54	0.42	0.12	34	7.15	387	313	7.95
2011 (18)	3.81	2.34	1.39	0.05	0.73	0.63	0.11	29	16.9	2380	378	7.98
2012 (10)	8.30	2.63	5.47	0.11	0.29	0.24	0.05	4	60.9	24	715	8.05
All (29)	5.27	2.40	2.75	0.07	0.57	0.49	0.09	21	31.7	1608	484	8.00
Station 316 (rainfall)[x]												
2010 (2)	1.90	1.54	0.31	0.03	2.24	2.14	0.10	16	18.3	4553	263	7.86
2011 (13)	3.78	3.57	0.16	0.05	2.79	2.69	0.10	13	21.7	1783	506	7.94
2012 (10)	5.08	3.97	1.05	0.06	1.89	1.88	0.02	3	48.5	76	773	8.02
All (25)	4.15	3.57	0.53	0.05	2.39	2.32	0.07	9	32.1	1430	593	7.97
Station 314 (rainfall)[v]												
2008 (1)	6.42	2.65	3.59	0.15	2.18	1.79	0.39	72	na	1600	145	7.30
2010 (2)	4.18	1.71	2.36	0.08	1.39	1.14	0.24	44	0.65	1129	59	7.04
2011 (18)	4.00	2.55	1.37	0.07	0.99	0.83	0.17	61	15.7	2187	381	8.04
2012 (11)	11.2	4.70	4.46	1.95	0.94	0.65	0.29	43	60.3	143	721	8.23
All (32)	6.55	3.24	2.56	0.72	1.04	0.82	0.22	54	30.6	1459	470	8.02

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspen ded solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Number of samples are shown in parenthesis. Parameter concentration averages include days where the sampling methods (grab and ISCO) were different at Stations 315, 316, and 314.
[x] Annual average concentrations at Stations 315 and 316 includes sampling days when there was and was not connective flow with the downstream station.
[w] na = not analyzed. Chloride was not included until late July 2008.
[v] Annual average concentrations at Station 314 includes sampling days when flow was and was not connective with the upstream stations.

The average proportion of TP in the form of TDP varied from 86 to 97% between the two upstream stations and runoff event types (Table 4.65). Total N was dominated by dissolved forms of N (NO_3-N and NH_3-N) at Station 315 for snowmelt (75%) and rainfall (54%) and at Station 316 for snowmelt (64%). However, in rainfall runoff, only 14% of TN consisted of NO_3-N and NH_3-N at Station 316.

The average concentrations of water quality parameters were generally comparable between the two upstream stations, with the exception of TP and TDP, which were more than four-fold greater on average for snowmelt and rainfall runoff at Station 316 compared to Station 315 (Table 4.64).

As indicated previously, most of the flow at Stations 315 and 316 occurred in 2011 and 2012 and the annual flow was four- to five-fold greater in 2011 than in 2012 (Table 4.64). Comparing average concentrations between the two years showed no consistency among the water quality parameters. The concentrations of N parameters were higher in 2012; whereas, TP and TDP were higher in 2011. The average concentrations of Cl and EC were higher in 2012 in snowmelt and rainfall runoff at both stations. In rainfall runoff, average *E. coli* concentrations were 99-fold (Station 315) and 23-fold (Station 316) greater in 2011 compared to 2012. These results suggest differences between N compared to P and *E. coli* in terms of responses to difference flows. Perhaps during higher flows and greater contributing areas, sources of P and *E. coli* are more accessible than N sources.

At the downstream Station 314, more water samples were obtained in the first 3 yr compared to Stations 315 and 316. Though, the majority of samples (64%) from Station 314 were also collected in 2011 and 2012 (Table 4.65).

Similar to the two upstream stations, the concentrations of TN, NO_3-N, and all of the P parameters were higher in snowmelt compared to rainfall runoff at Station 314 (Table 4.65). The concentration of TSS was also higher in snowmelt at Station 314. The concentrations of ON, NH_3-N, Cl, *E. coli*, and EC were less in snowmelt compared to rainfall.

On average, TN consisted of 60% NO_3-N plus NH_3-N in snowmelt and 50% NO_3-N plus NH_3-N in rainfall runoff at Station 314 (Table 4.65). Total P consisted of 82% TDP in snowmelt runoff and 79% TDP in rainfall runoff. These proportions of TDP were slightly lower than observed at the two upstream stations. Higher concentrations of PP and TSS were measured at Station 314 compared to the upstream stations, and the higher concentration of PP at Station 314 resulted in a lower proportion TP as TDP compared to Stations 315 and 316. The drainage channels leading to Stations 315 and 316 were well vegetated (Figure 4.60) and were likely effective in filtrating sediment. On the other hand, most of the runoff at Station 314 originated from the cultivated field, which was likely more susceptible to soil erosion by runoff.

The concentrations of water quality parameters were inconsistent during snowmelt in terms of years that had the lowest and highest average concentrations at Station 314 (Table 4.65). During rainfall, however, the concentration of N parameters, Cl, and EC were highest in 2012; whereas, the concentration of P parameters and TSS were highest in 2008. When the values of all samples (snowmelt plus rainfall) were averaged (averages not shown) for Station 314, the highest concentration for most parameters occurred in 2011 or 2012 (Figure 4.61), which were the years with the highest annual flows. Exceptions included TP, TDP, and *E. coli*, which had highest average concentrations in 2010. The lowest average concentrations for ON, TP, TDP, PP, TSS, Cl, E. *coli*, and EC occurred in 2009, which had the lowest annual flow during the study. The lowest average concentrations for TN, NO_3-N, and NH_3-N were either in 2008 or 2010, which were also low-flow years compared to 2011 and 2012.

As already indicated, most of TP was in the form of TDP at Station 314. However, on April 30 and May 1, 2011, peak concentrations of TP were observed and 75 to 82% of TP was in PP form (Figure 4.61b). This corresponded to a peak concentration of TSS (Table 4.61c), which was the result of peak flows near the end of April (Figure 4.58). It is interesting that even higher peak flows occurred in July 2011, however, TP and PP did not respond as they did in April, and TSS only increased a small amount compared to April 30 and May 1. This difference was likely caused by the crop, which was well established by July and provided greater protection from soil erosion than would have been the case in late April. Without corresponding increases in TSS concentration during other peak concentrations of TP, such as in March of 2008, 2010, and 2012, the majority of the P in runoff was in TDP form (Figure 4.61). Ignoring the TP-PP peak on April 30 and May 1, this was also true for TP-TDP in March 2011. These TP-TDP peaks occurred early in the runoff season, followed by a decrease in concentration with time.

Annual loads of nutrients and TSS at Station 314 were highest in 2011 (Table 4.66), and this can be attributed to the much higher annual flow in 2011 compared to the other years (Table 4.64). Similarly, the smallest loads occurred in 2009, the year with the smallest annual flow. The amount of annual flow was a primary factor in the differences in loads among the years. However, changing concentrations also had an influence. For example, the annual load of TSS was nearly 3800-fold greater in 2011 compared to 2009; whereas, the annual flow in 2011 was 224 times greater than in 2009. In addition to the higher flow, average TSS concentration (snowmelt plus rainfall) was 11-fold higher in 2011 than in 2009. In this case, increased flow and increased concentration influenced the higher TSS load in 2011.

Table 4.66. Annual loads of nutrients and total suspended solids at Station 314 at the South Field site from 2008 to 2012.[z]

Year	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
	(kg yr^{-1})							
2008	17.3	12.3	1.32	3.28	5.98	5.40	0.80	76.9
2009	4.3	2.7	1.14	0.38	1.41	1.30	0.12	15.1
2010	21.3	19.3	1.04	0.96	16.2	15.5	0.68	28.2
2011	1732	690	1007	25.7	423	282	141	56,907
2012	417	138	253	23.5	59.0	51.3	7.78	2,555

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids.

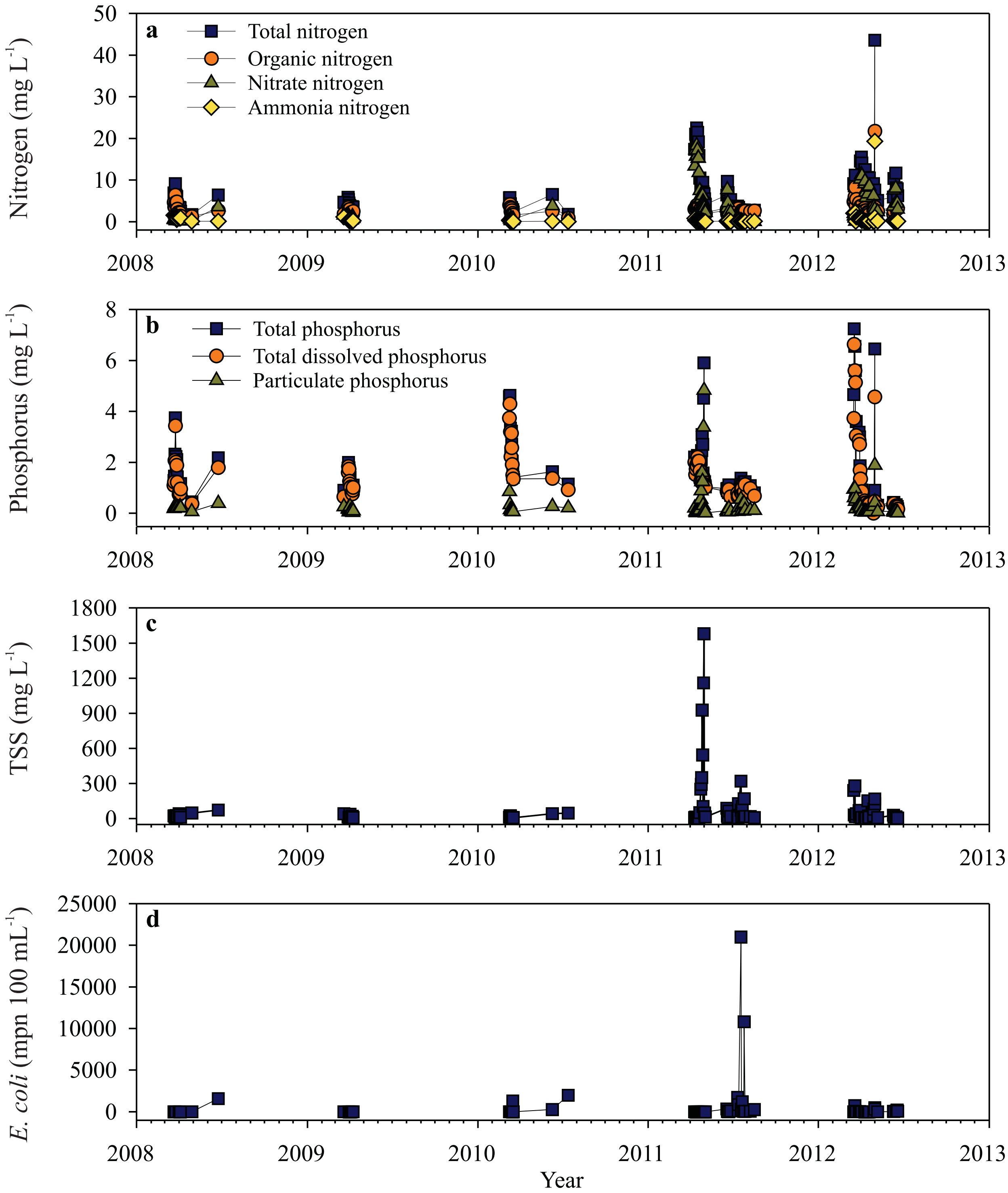

Figure 4.61. Concentrations of (a) total nitrogen, organic nitrogen, nitrate nitrogen, and ammonia nitrogen; (b) total phosphorus, total dissolved phosphorus, and particulate phosphorus; (c) total suspended solids, and (d) *Escherichia coli* (*E. coli*) at the downstream Station 314 at the South Field from 2008 to 2012.

BMP effects on water quality. Comparing averages of water quality parameters in snowmelt runoff between the two BMP periods showed that the concentrations of NH_3-N and *E. coli* were significantly less in the post-BMP period compared to the pre-BMP period (Table 4.67). The magnitude of the difference in NH_3-N concentration was relatively small and care needs to be taken for *E. coli* as microbial activity is typically low during the colder conditions of snowmelt. Unfortunately, the rainfall events could not be compared between the two periods, as very few rainfall runoff samples were collected in the pre-BMP period.

The average concentration of several parameters, including TN, ON, NO_3-N, Cl, and EC, were significantly higher in the post-BMP period than in the pre-BMP period (Table 4.67). Average pH was also significantly higher in the post-BMP period. Of these parameters, the difference was relatively large for the average concentration of NO_3-N, which was 11-fold greater in the post-BMP period. The average concentration of TP, TDP, PP, and TSS were also higher in the post-BMP period, but were not statistically different from the pre-BMP period. In particular, TSS concentration was nearly 10-fold greater during the post-BMP period.

These results strongly suggest the BMPs that were successfully implemented in spring 2010 and continued in 2011 and 2012 were not effective in water quality improvement in runoff at the edge-of-field of the SFD site. Therefore the hypothesis was rejected. The design and implementation of a manure nutrient plan did not alter the previous management practices. The manure application rates that were recommended and the rates actually applied did not differ substantially from the rates used prior to the post-BMP period (Table 4.57). In other words, the nutrient management plan did not result in a reduction in manure application rates. In fact, the recommended rate calculated for canola in 2011 was actually higher than rates typically applied to this site (Table 4.58). The soil at this site required the application N for optimum crop growth. Added P was not required. However, the STP concentration was not excessive in the field (Table 4.61). An alternative nutrient management plan would be to apply manure based on one year of crop P removal. Often, P-based application of manure will result in lower application rates. However, this may require supplemental commercial N fertilizer, and there may or may not be additional cost of applying manure not used at this site elsewhere. Using the yield results (Table 4.56), average TP content of liquid dairy manure (Table 4.63), and typical crop removal values for P (Canadian Fertilizer Institute 2001), it was estimated that typical P-based application rates would be about 45 Mg ha^{-1} for canola, 30 Mg ha^{-1} for barley, and 80 Mg ha^{-1} for corn silage. Therefore, in this case, using a P-

Table 4.67. Average water quality parameter concentrations during the pre -BMP and post-BMP periods during snowmelt at Station 314 of the South Field.[z]

Period	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl[y]	*E. coli* (mpn 100 mL^{-1})	EC (µS cm^{-1})	pH
		-----	-----	-----	-----	(mg L^{-1})	-----	-----	-----	-----			
Pre-BMP	35	4.19*b*	2.88*b*	0.67*b*	0.57*a*	1.80	1.62	0.18	17	5.93*b*	49*a*	188*b*	7.33*b*
Post-BMP	40	11.3*a*	3.34*a*	7.43*a*	0.46*b*	2.26	1.75	0.51	160	21.7*a*	24*b*	390*a*	7.55*a*

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Chloride was included late in July 2008 (n = 22).

based approach may not substantially reduce manure application rates. It appeared that the N and P content of the liquid dairy manure was in reasonable balance with crop needs, and this was likely why STP concentration was sufficient but not excessive at this site.

The 30-m setbacks were only applied to about 10% of the total channel length in the field (Figure 4.56). Perhaps if the entire channel system was subjected to setbacks, this part of the BMP plan would have been effective. As well, the major change in manure management of switching from surface applied to injection was not achieved. It was anticipated that manure injection would have provided better protection from the loss of nutrients from manure to surface runoff.

With all things held equal, ineffective BMPs or failure to implement BMPs should have resulted in no differences between the pre- and post-BMP periods. However, nutrient and TSS concentrations were clearly higher in the post-BMP period (Table 4.67). It would appear that the much larger annual flow in the post-BMP period was a dominant factor that caused higher concentrations in snowmelt runoff. In 2010, there was very little rainfall runoff at Station 314 (Table 4.64), and the snowmelt runoff in 2010 was in the pre-BMP period. The average annual flow from snowmelt runoff from 2008 to 2010 (i.e., pre-BMP) was 3108 m^3 yr^{-1}. In 2011 and 2012 (i.e., post-BMP), the average annual flow was 75,329 m^2 yr^{-1}, which was 24-fold greater than in the pre-BMP period. If the implemented setbacks had any positive effects, they were likely overwhelmed by the effects of the much larger annual flows in the post-BMP period.

Experimentally, it would have been better if the annual flows and other hydrological characteristics were similar between the pre- and post-BMP periods. Also, the BMPs implemented were likely marginal at best in terms of effectiveness. A more aggressive BMP plan, including the successful conversion to injected liquid manure, using setbacks along the entire drainage channel, and establishing grass cover throughout the drainage channels may have had a positive effect on runoff water quality. However, as discussed earlier, the use of setbacks and grass cover throughout the channels were deemed to be impractical for field operations at this site.

4.9.4 Conclusions

- Even though the shallow, but distinctive drainage channel system in the field started as inlets along the west side of the field and exited near the northeast corner, connective flow likely does not often occur in most years. As a result, the two upstream stations were not used to access the BMPs in terms of water quality.
- The downstream Station 314 received most of its annual flow from within the field, and the station essentially functioned as an edge-of-field monitoring station.
- The SFD site demonstrated that the implementation of BMPs may not necessarily proceed according to plan. In this case, unavailability of manure injection equipment or having conditions too wet or too dry to establish a vegetative buffer area resulted in a partially implemented BMP plan.

- The use of a nutrient management plan did not substantially alter the amount of manure applied to the field. The soil required added N, but no P. Even though the soil had sufficient P, the STP was not excessive. The nutrient management plan was effective in identifying when the application of commercial fertilizer was not needed in addition to applied manure.
- The annual flows were variable at the edge-field-station, ranging from 1148 m^3 in 2009 to 257,087 m^3 in 2011.
- At the edge-of-field, the concentrations of TN, NO_3-N, TP, TDP, PP, and TSS were higher in snowmelt compared to rainfall runoff. In contrast, the concentrations of ON, NH_3-N, Cl, *E. coli*, and EC were less in snowmelt compared to rainfall.
- On average at the edge-of-field, the proportion of TN in the form of NO_3-N plus NH_3-N was 60% in snowmelt runoff and 50% in rainfall runoff. Total P consisted of 82% TDP in snowmelt runoff and 79% TDP in rainfall runoff.
- The annual average concentrations for all samples (snowmelt plus rainfall) at the edge-of-field were highest for most parameters in 2011 or 2012, which were the years with the highest annual flows. Exceptions included TP, TDP, and *E. coli*, which had the highest average concentrations in 2010. The lowest average concentrations for TN, ON, NO_3-N, NH_3-N TP, TDP, PP, TSS, Cl, *E. coli*, and EC occurred in 2008, 2009, or 2010, which were all low-flow years compared to 2011 and 2012.
- Annual flow was a primary factor for the export of nutrient and TSS loads at the edge-of-field from the site. The largest loads were exported in the year (2011) that had the largest annual flow, and the smallest loads were exported in the year (2009) that had the smallest annual flow.
- The components of the BMP plan that were implemented were ineffective at improving water quality at the SFD site. In fact, the concentration of most water quality parameters were higher in the post-BMP period compared the pre-BMP period. The higher concentrations were explained by the much higher annual flows in the post-BMP period. The nutrient management plan did not alter to any extent the amount of manure applied in the post-BMP period compared the pre-BMP period. Any positive effects caused by the manure application setbacks were obscured by the effects of the much higher annual flows in the post-BMP period compared the pre-BMP period.

4.10 North Pasture Site

4.10.1 Introduction and Hypothesis

The NPS site was one of two pasture BMP sites selected in the WHC Sub-watershed. The NPS consisted of a small pasture, which was part of a dairy operation. The pasture was on the mainstem of WHC in the northeast part of the sub-watershed. When in the pasture, cattle had direct access to the creek and this caused erosion and slumping along part of the creek. Holstein heifers were typically present in the pasture from May to November and the site was overgrazed. The BMPs were designed to address overgrazing and creek erosion, both of which have the potential to degrade water quality. The BMP plan included livestock exclusion, increased pasture size, decreased cattle stocking rate, and bioengineering. Two instream monitoring stations were used at this site to assess water quality. In addition, the effects of grazing management were evaluated by measuring forage production.

The underlying assumption for the selection of the BMPs was that overgrazing and direct access of cattle to the creek were causing reduced water quality because of increased contributions of nutrients, sediment, and bacteria to WHC during snowmelt and rainfall runoff. However, direct access by cattle does not necessarily require runoff events to cause negative effects on water quality. The hypothesis was:

- The implementation of BMPs (livestock exclusion, increased pasture size, decreased cattle stocking rate, and bioengineering) will improve pasture health and decrease the concentration of water quality parameters in the creek.

4.10.2 Methods

4.10.2.1 Site Description and Management

The NPS site was a small pasture on WHC in the northeast part of the sub-watershed (Figure 4.3). Initially, the pasture was 4 ha in size in the southwest corner of the quarter section (Pasture A) (Figure 4.62). In 2009, the producer expanded the grazing area to include Pasture B (Figure 4.62), which extended northeast from Pasture A and increased the total size to 9 ha. Whelp Creek entered the site in the northwest corner of Pasture A via a road culvert and flowed diagonally until it exited at the southeast corner of Pasture A (Figures 4.62 and 4.63). The northwest inlet point was the deepest part of the creek in the pasture.

The NPS site was in the PED10/U1h soil landscape model, as described by AGRASID (Alberta Soil Information Centre 2013). Soils within this model include dominant (>60%) Penhold (Orthic Black Chernozem) soil series and significant (10 to 30%) Miscellaneous Solonetzic-ZBL (Black Solodized Solonetz) and Miscellaneous Gleysol (Orthic Humic Gleysol) soil series, with poor and well drained characteristics. The landform in the model is described as undulating, with high relief and a limiting slope of 4%, and parent material consists of medium textured sediment deposited by wind or water and undifferentiated material. The surface soil at the site had a loam texture (45% sand, 22% clay), a pH of 7.9, electrical conductivity of 2.0 dS m^{-1}, 6940 mg kg^{-1} TN, 927 mg kg^{-1} TP, and 13.4% organic matter (Appendix 4).

The NPS site was part of a dairy operation and had been managed as a pasture by the current producer for 7 yr prior to the start of the study. Cattle were typically in Pasture A from May or June until October or November (Table 4.68). In 2009, the producer used Pasture B in conjunction with Pasture A. Commercial fertilizer was often applied on Pasture A either in May or June. Two main

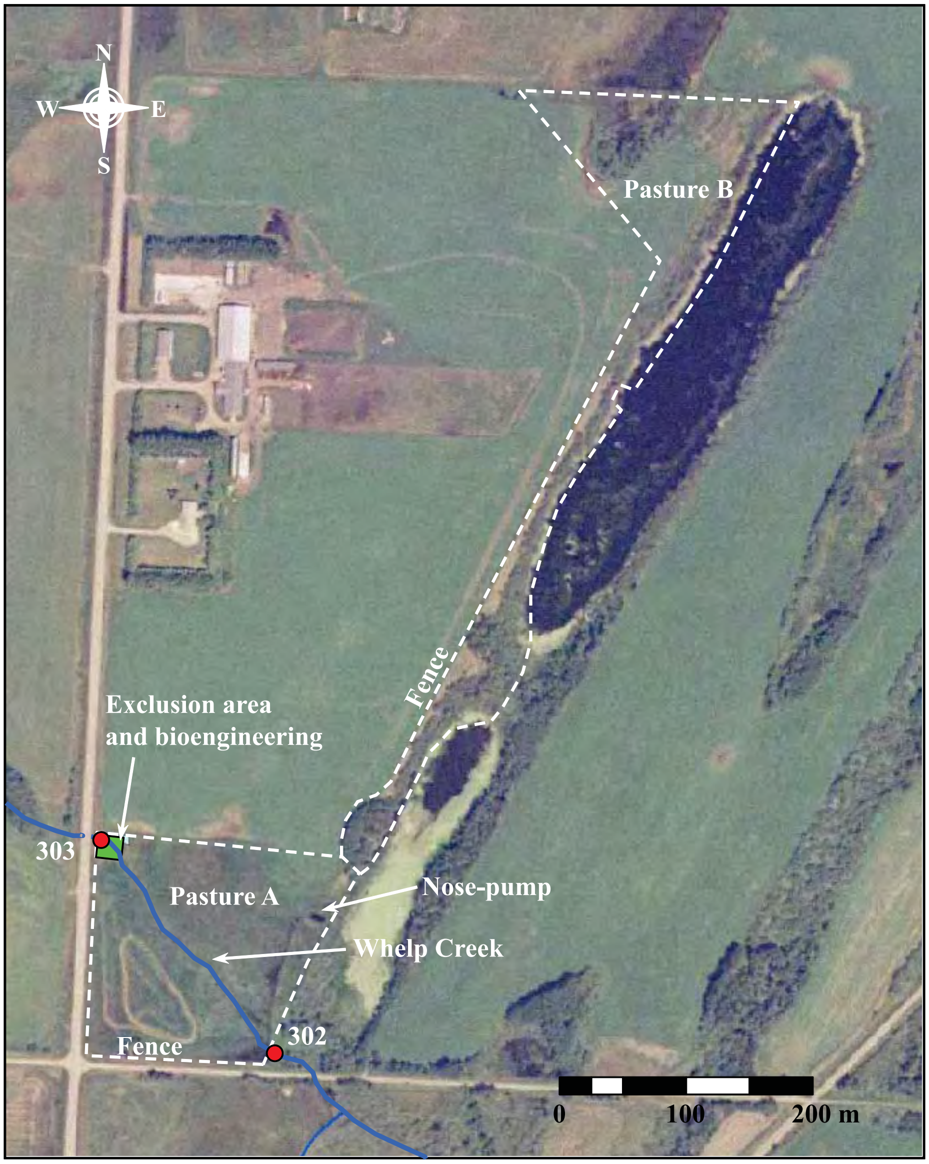

Figure 4.62. The North Pasture showing Whelp Creek, Pastures A and B, water monitoring stations (Station 302 and 303), the excluded and bioengineering area, and the nose-pump location.

sources for watering cattle existed in Pasture A. One source was a nose-pump fed from a shallow groundwater well (Figure 4.62). The nose-pump was installed by the producer prior to the study. The other source was WHC within Pasture A. When water stopped flowing in the creek, pooled water was used by the cattle, particularly in the area by the culvert outlet in the northwest corner of the pasture (Figure 4.63b).

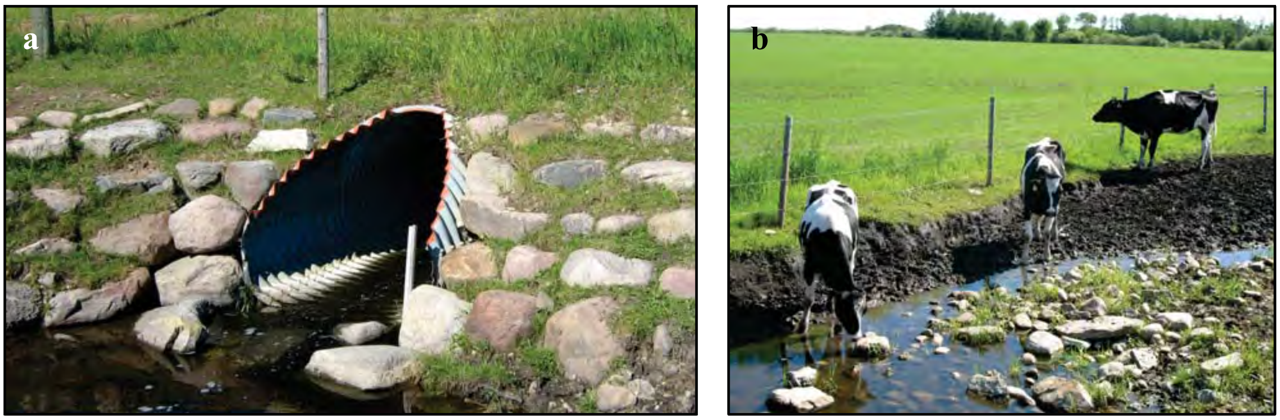

Figure 4.63. The northwest corner of the North Pasture showing (a) the culvert outlet into pasture on July 10, 2007 and (b) the degraded riparian area a few metres downstream from the culvert outlet on June 19, 2008.

Table 4.68. Cattle and pasture management at the North Pasture from 2007 to 2012.

		Pasture A		Pasture B		Pastures A and B		Fertilizer[z]		
								N	P	K
Year	Date in pasture	Livestock[y]	Days in	Livestock	Days in	Livestock	Days in	(kg ha^{-1})		
2007	mid-May to mid-Oct	20h	150[x]	-	-	-	-	34[w]	15	28
2008	mid-May to mid-Oct	20h	150[x]	-	-	-	-	34[w]	15	28
2009	May 28 to Aug 22	-	-	-	-	19h[v]	86	100[u]	0	0
	Aug 23 to Aug 31	-	-	-	-	16h	8			
	Sep 1 to Nov 30	-	-	-	-	5bc+2ca	90			
2010	May 31 to Jul 6	-	-	-	-	11h	36	52[u]	0	0
	July 7 to Jul 20	-	-	-	-	23h	13			
	July 21 to Aug 18	-	-	-	-	17h	36[t]			
	Sept 10 to Nov 1	-	-	-	-	10h	51			
2011	-	-	-	-	-	-	-	-	-	-
2012[s]	Jun 15 to Jul 14	-	-	-	-	4c+9h+1b	31	52[u]	0	0
	Jul 14 to Oct 6	9h+1b	83	4c	83	-	-			

[z] Applied on Pasture A.
[y] c = cows, b = bull, h = heifers, bc = beef cattle, ca = calves.
[x] Estimated days on pasture.
[w] 15-15-15 fertilizer applied at 225 kg ha^{-1}.
[v] Five heifers added June 1.
[u] Assumed 46-0-0 as the fertilizer source.
[t] Cattle removed for weed control measures (mowing).
[s] Two horses were in the pasture from late April until the first week in June.

Visual observations indicated the pasture was overgrazed. A number of undesirable plant species were present, such as dandelion (*Taraxacum officinale*) and Canada thistle (*Cirsium arvense*). Cattle had direct access to WHC when in the pasture. At one location in particular, cattle had severely degraded the riparian area. This degraded area was a few metres downstream from the culvert inlet in the northwest corner of the pasture (Figure 4.63b). There was extensive erosion of the creek banks, as well as slumping of soil from an adjoining crop field. Cattle tended to drink the pooled water in front of the culvert and linger in that area. This behaviour was reinforced by the culvert, which was used for rubbing. In the past, some measures were taken to alleviate the erosion with rip-wrap, however, degradation continued. Another potential source of nutrients to the creek was granular nitrogen fertilizer, which was typically applied to the pasture in spring (Table 4.68).

4.10.2.2 Implementation of Beneficial Management Practices

The BMP plan for this site evolved with time. Originally, the components of plan were scheduled for implementation in 2010. One component of the plan was to increase the pasture size by including Pasture B (Figure 4.62) and use both pastures during the grazing season. However, the producer decided to initiate this change in 2009 and it was continued in 2010. Adding Pasture B increased the grazing area from 4 to 9 ha. Pasture B included a slough and shade for the livestock. In 2010, the cattle were removed from the pasture in late August and weed control was carried out by mowing. At the time of mowing, the grass was well grazed and only areas with high weed density were mowed. Grazing was resumed on September 10, 2010.

The second component of the plan was to exclude cattle from the degraded area by the culvert outlet in the northwest corner of the pasture (Figure 4.64a). A four-strand, barbwire fence was constructed in May 2010 inclosing an area about 20 by 20 m in size immediately downstream from the culvert (Figure 4.64b). Within the excluded area, bioengineering techniques were used to promote recovery of the degraded area. Bioengineering is not a BMP, but rather a reclamation activity, and the bioengineering carried out at this site is described in the next sub-section.

In 2011, it was decided to rest the pasture and not graze livestock for one season to allow the vegetation to recover. In addition, chemical weed control was carried out to help promote recovery of grass species in areas heavily infested with weeds. A herbicide (clopyralid + MCPA ester) was applied to Pasture A using an all-terrain-vehicle-mounted sprayer on June 27, 2011, with follow-up spot spraying for Canada thistle on September 8, 2011.

In 2012, cattle were returned to the pasture and the site was grazed from mid-June to early October. Pastures A and B were used throughout the grazing season. In addition to increasing the grazing area by including Pasture B, the producer was encouraged to reduce the number of livestock placed in the pasture. In 2012, the maximum number of livestock was 14 animals, which was less than the maximum numbers in 2007 to 2010 (Table 4.68).

The implementation of the BMPs occurred during 3 yr from 2009 to 2011. Even though the inclusion of Pasture B was started in 2009 and the excluded area was established in 2010, for the purpose of this study, the start of the post-BMP period was considered to be June 2011. Since the pasture was not grazed in 2011, the post-BMP period began when cattle were not returned to the pasture in late spring 2011, which is when the cattle would have been returned.

4.10.2.3 Bioengineering

Bioengineering within the excluded area (Figure 4.64b) consisted of building two, 14-m long terraces on the eroded north stream bank using wooden boards and packed soil (Figure 4.65a). The boards created two, parallel wattle fences, one of which was taller, creating the terrace. Willow stakes (*Salix spp.*) were then planted on the terraces (Figure 4.65b).

The willows stakes for the terrace were gathered from within the watershed and allowed to soak in a pond for 12 d. The willow stakes were transported to the site and cut into 0.3- to 0.6-m lengths. Willow cuttings were planted approximately 0.3-m apart and staggered throughout the terrace. Each willow was planted so that three-quarters of each cutting was in the soil. Photo points were established at the time of the construction in May 2010 to record progression of the bioengineered site with time.

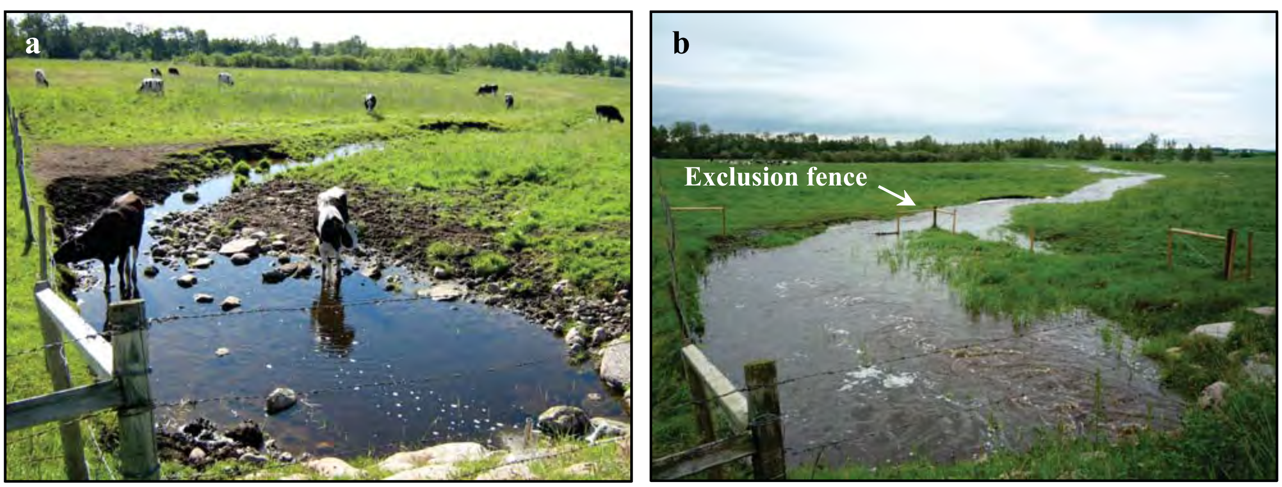

Figure 4.64. The northwest corner of Pasture A showing (a) the degraded area on Whelp Creek on July 10, 2007 and (b) the constructed fence used to create an exclusion area to prevent cattle access. The latter image was taken on July 14, 2010.

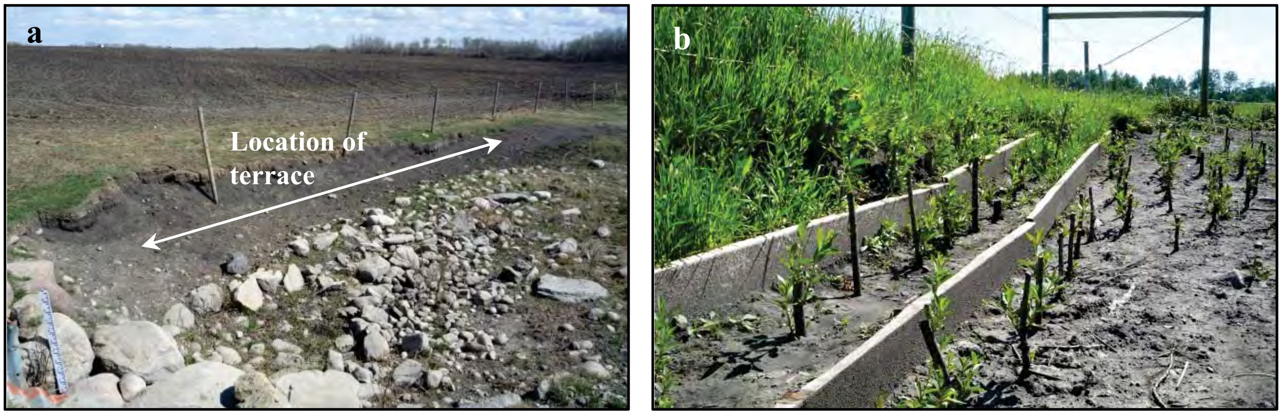

Figure 4.65. The bioengineering site showing (a) the area where the terrace was located and (b) a close-up image of the constructed terrace and live willow stakes. Images were taken March 23, 2010 and July 8, 2010, respectively.

4.10.2.4 Soil Sampling

Soil characterization samples (Sub-section 2.9) were collected on October 21, 2009. Other soil samples collected at this site included 0- to 15-cm agronomic samples and 0- to 60-cm soil-test samples (Sub-section 2.9).

Agronomic soil samples were collected in fall 2007 from four sample points in order to determine the nutrient status of the surface soil in Pasture A. The sample locations were selected from representative areas within the pasture.

Soil-test samples were collected in spring and fall 2011 to further document the soil nutrient status and to determine if fertilizer was required. However, as the cattle were excluded from the pasture in 2011, fertilizer was not applied. Sampling in the spring and fall was conducted using a nine-point grid pattern covering Pasture A.

4.10.2.5 Rangeland Production

To assess rangeland production in each year from 2009 to 2012, three 1.5-m^2 production cages were placed in the pasture and harvested annually for grass, forbs, and litter. This provided an estimate of ungrazed production. Clippings were also collected outside of each cage to monitor grazed production. Harvested vegetation was processed by separating grass, forbs, and litter, which were stored in perforated paper bags. After each collection, the samples were dried and weighed to determine yield. In 2012, only one cage was harvested because the other two cages were knocked over by cattle. For statistical comparisons between years, a single population of average yield differences for each year was created for each biomass type (grass, forb, and litter) by subtracting the outside cage yield from the inside cage yield. Further details of methodology, including statistical analysis, can be found in Sub-section 2.12.2.

4.10.2.6 Water Flow and Quality

Two water quality monitoring stations were installed at the NPS site in fall 2007: one upstream (Station 303) and another downstream (Station 302) (Figure 4.62). Station 303 was at the exit of a culvert leading into the NPS site (Figure 4.63a) and was instrumented with a Level TROLL to measure flow, while Station 302 was instrumented with a staff gauge (Sub-sections 2.6, 2.7, and 2.8). For BMP evaluation from a water quality perspective, the pre-BMP period was from 2008 to 2010 and the post-BMP period was from when the cattle were excluded in June 2011 (i.e., not returned to the pasture) until when they were re-introduced into the pasture in mid-June 2012.

Base flow was difficult to separate from rainfall at this site and any base flow was a small component of overall flow. Therefore, flow that may have been base flow was included as part of rainfall-flow events. Water quality parameters were compared between the upstream and downstream stations using samples collected on the same day with the same sampling method at both stations. Because water quality concentration data at the two stations were dependent 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 between these water quality differences before and after BMP implementation were performed for each event type, and all events combined, as described in Sub-section 2.8.4.

Nutrient and TSS loads were calculated for Station 303, and since Station 303 was also a watershed-wide station, the load results for this station are presented in Sub-section 4.4.

4.10.3 Results and Discussion

4.10.3.1 Implementation of Beneficial Management Practices and Bioengineering

The addition of Pasture B in conjunction with Pasture A more than doubled the grazing area from 4 to 9 ha. Compared to 2007 and 2008, the addition of Pasture B reduced the stocking density by at least half (Table 4.69). As well, the total animal unit equivalents (AUE) were less in 2009, 2010, and 2012 by about 25% on average, also reducing the stocking density. For 51 d in 2010, the stocking density was as low as 0.7 AUE ha^{-1}, when only 10 heifers were in the combined pastures. Similarly, stocking rate, expressed as annual animal unit month per hectare (AUM ha^{-1}), was reduced from 16.5 AUM ha^{-1} in 2007 and 2008 to 6.6 AUM ha^{-1} in 2009 (Table 4.69).

The advantage of reduced AUE ha^{-1} and AMU ha^{-1} values is the grazing pressure was reduced on the vegetation in the pasture. Kaulbars (2009) suggests that the carrying capacity of a pasture in poor condition that receives 350 to 450 mm yr^{-1} of precipitation (Whelp Creek Sub-watershed = 446 mm) is 1 AUM ha^{-1}. A pasture in fair condition has a carrying capacity of 1.5 AUM ha^{-1}, and a pasture in excellent condition has a carrying capacity of 3 AUM ha^{-1}. Using the livestock types (annual weighted AUE values) and grazing times for the NPS site in 2007 to 2010 and 2012 (Table 4.69), the amount of land required so not to exceed pasture carrying capacity was estimated from 13 to 66 ha. The estimated pasture size varied depending on type and number of animals per year,

Table 4.69. Stocking density and rate of livestock at the North Pasture from 2008 to 2012.

Year	Pasture[z]	Livestock[y]	Time in pasture (d)	Stocking density (AUE ha^{-1})[x]	Annual stocking rate (AMU ha^{-1})[w]
2007	A	20h	150	3.4	16.5
2008	A	20h	150	3.4	16.5
2009	A + B	19h	86	1.4	6.6
	A + B	16h	8	1.2	
	A + B	5bc+2ca	90	0.8	
2010	A + B	11h	36	0.8	4.3
	A + B	23h	13	1.7	
	A + B	17h	36	1.3	
	A + B	10h	51	0.7	
2011	A + B	none	0	0	0
2012	A + B	4c+9h+1b	31	1.4	6.6
	A	9h+1b	83	1.9	
	B	4c	83	1.0	

[z] Pasture A = 4 ha, Pasture B = 5 ha.
[y] c = cows, b = bull, h = heifers, bc = beef cattle, ca = calves.
[x] AUE ha^{-1} = animal unit equivalents per hectare. Animal unit equivalents used were 0.67 for a heifer, 1.2 for a cow, 0.5 for a calf (weaned), and 1.5 for a bull (Kaulbars 2009). AUE ha^{-1} = number of animals × AEU ÷ hectares.
[w] AUM ha^{-1} = animal unit month per hectare. AUM ha^{-1} = number of animals × AUE × number of months in pasture ÷ hectares. One month = 30.5 d. For those years with varying numbers of livestock with time and/or different livestock types at the same time, weighted AEU values were used.

the length of time per year in the pasture (Table 4.69), and pasture conditions ranging from poor to excellent. For a pasture in fair condition, the size of pasture ranged from 27 to 44 ha. Even under excellent conditions, a pasture larger than Pastures A and B combined would be needed to avoid exceeding carrying capacity. Therefore, even with the increase in grazing area from 4 to 9 ha and a reduction in grazing pressure, Pastures A and B were likely still overgrazed in 2009, 2010, and 2012.

Resting the pasture from grazing and carrying out weed control measures in 2011 improved the quality of the pasture vegetation. Visually, the pasture recovery was very successful after the rest period. The amount of vegetative residue in the pasture in spring 2012 was substantial compared to other years following a normal grazing season (Figure 4.66). The grasses in the pasture set seed and provided excellent forage. Chemical control of Canadian thistle was successful, although additional spot control was still required. In order to completely rest a pasture for one or more seasons requires alternative pasture for cattle and/or a reduction in herd size. As a result, resting a pasture may not be an easy option for some operations. However, in this case for the NPS, the producer had access to alternative pasture and watering source in 2011.

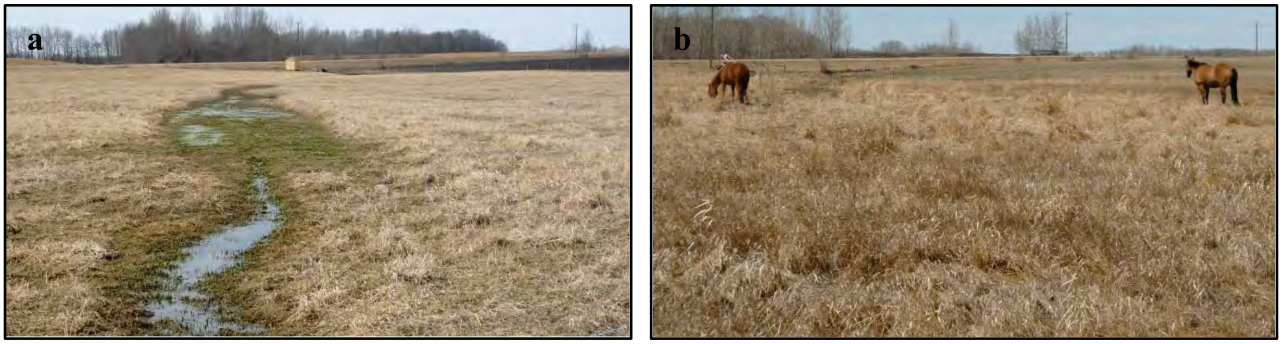

Figure 4.66. Vegetative residue in Pasture A (a) on April 17, 2008 following a typical grazing season in 2007 and (b) on April 23, 2012 following a year without grazing in 2011.

The constructed fence that excluded cattle from a degraded reach on WHC in the northwest corner of the Pasture A was successful and was likely crucial to the success of the bioengineering that was carried out in 2010. The planted willows at the site had 3 yr to become established. In this time, the shoots of the surviving willows grew approximately 1 m in length, and the survival rates of the cuttings were 93% from 2010 to 2011 and 89% from 2011 to 2012. Willow survival rates of this magnitude are considered excellent and represent a positive step towards reclamation of the eroded stream bank. Images taken from the photo points recorded the successful growth of the willows and other vegetation at the site (Figure 4.67). The growth of the planted willows and re-growth of other vegetation will stabilize the soil and reduce or prevent erosion from occurring during high-flow events.

Costs of the implemented BMPs were relatively low including supplies for bioengineering and the cost of herbicide. There was, however, a significant amount of time (48 h) required completing the bioengineering project (Table 4.70).

Figure 4.67. The bioengineering site on Whelp Creek at the North Pasture on (a) September 17, 2010 (about 1 mo after construction), (b) June 6, 2011, and (c) August 14, 2012.

Table 4.70. Cost of Beneficial Management Practices at the North Pasture.

Item	Cost ($)	Labour (h)
Willow stakes	0.00	40
Terracing[z]	44.00	4
Building exclusion fence	130.00	4
Spraying	291.78	4
Total	**465.78**	**52**

[z] 10% miscellaneous was added to account for nails, screws, etc.

4.10.3.2 Soil

The concentrations of extractable NO_3-N and STP were low in the agronomic (0 to 15 cm) and soil-test soil (0 to 60 cm) samples (Table 4.71). In the soil-test samples, the concentrations of NO_3-N, NH_4-N, and STP were similar between spring and fall and decreased with depth. In terms of nutrient requirements for optimum forage growth in the Black Soil Zone, fertilizer is recommended for this site based on McKenzie (2005). As mentioned above, inorganic fertilizer was typically applied annually at this site. Based on McKenzie (2005), the soil-test NO_3-N and STP results suggest that about 90 kg ha^{-1} N and 10 kg ha^{-1} P would be required for optimum forage growth at this site. It would appear that adequate P was applied in 2007 and 2008 and adequate N was applied in 2009. However, in other years, these nutrients may have been under applied in terms of crop needs. Good soil fertility is important for the maintenance of quality pasture production (Kaulbars 2009).

4.10.3.3 Rangeland Production

Grass dry-matter yield in the production cages decreased with time (Table 4.72). In years with grazing (2009, 2010, and 2012), the grass production was much less outside of the cage. In 2009 and 2010, the average yield outside of the cage was about 2% of the yield inside the cage. In

Table 4.71. Average concentrations for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for the agronomic and soil-test samples collected at the North Pasture.

Year	Soil layer (cm)	NO_3-N Spring	NO_3-N Fall	NH_4-N Spring	NH_4-N Fall	STP Spring	STP Fall
		---- (mg kg^{-1}) ----					
				Agronomic samples			
2007[z]	0-15	6.6	ns[y]	7.2	ns	12.0	ns
				Soil-test samples			
2011[x]	0-15	10.3	10.4	6.1	7.0	20.2	24.1
	15-30	6.2	6.4	1.9	2.8	4.6	6.9
	30-60	2.7	4.2	1.8	2.6	1.0	4.7

[z] n = 4.
[y] ns = not sampled.
[x] Each layer was a composite sample prepared from nine sampling points.

contrast, in 2011 when the pasture was not grazed, the yield outside of the cage was 83% of the cage yield. The difference in yield between inside and outside of the cages in 2011 was significantly different then the differences in 2009 and 2010 (Table 4.72). Even though only one cage was harvested in 2012, the grass yield in the cage was quite low and there was no harvestable yield outside of the cage suggesting overgrazing. Observations in 2012 supported that the pasture was overgrazed.

Forb average dry-matter yield also generally decreased with time (Table 4.72). Forb yield was higher inside the cage compared to outside the cage. There was no forb yield outside the cages in 2009 and 2010, likely because of grazing. However, in 2012, when grazing occurred, the forb yield outside of the cage was much higher compared to the previous years, though only one cage was harvested in 2012. As with the grass yield in 2011, the difference in forb yield between inside and outside the cage was less in 2011. However, this was mainly due to a much lower forb yield inside the cage compared to 2009 and 2010. Since no grazing occurred in 2011, it was expected that the yields between inside and outside the cages should have been similar. However, average forb yield outside the cages was 37% of the yield inside the cage. The inside-outside cage differences in forb yields were not significantly difference among the 3 yr (2009 to 2011), suggesting that no grazing in 2011 did not promote forb recovery at this site.

Litter average yield increased inside and outside of the cages with time (Table 4.72). Litter yield in 2011 was higher than in 2009 and 2010 suggesting the exclusion of livestock from grazing for one season allowed for some buildup of litter, which is important for pasture recovery. There was a noticeable difference between the inside and outside of the cages in 2011, when they should have been similar because of no grazing. Perhaps this was an artifact because of the few samples (n = 3)

Table 4.72. Cage harvest results of average dry-weight yield for grass, forbs, and litter from 2009 to 2012 at the North Pasture.

		Year			
		2009 (n = 3)	2010 (n = 3)	2011 (n = 3)	2012 (n = 1)[z]
		---------- ($kg\ ha^{-1}$)	----------	----------	----------
Grass	Inside cage	4683	4174	2137	1002
	Outside cage	97	83	1773	0
	Difference [y]	*4585a*	*4091a*	*364b*	*1002*
Forb	Inside cage	243	43	19	78
	Outside cage	0	0	7	30
	Difference [y]	*243a*	*43a*	*12a*	*48*
Litter	Inside cage	81	307	425	3255
	Outside cage	0	119	218	9
	Difference [y]	*81a*	*188a*	*208a*	*3246*

[z] There was only one cage harvested in 2012, and therefore, was not included in statistical analysis.
[y] Average annual (2009 to 2011) inside-outside yield differences followed by different letters are significantly different at $P < 0.1$.

that were taken. The inside-outside cage differences in litter yields were not significantly difference among the 3 yr (2009 to 2011). It is interesting that in 2012 the litter yield was much higher inside the cage. This likely represented un-grazed forage from 2011 that formed the litter in 2012. The 2012 inside cage litter yield was comparable to the grass yield in 2011 (2137 kg ha^{-1}), recognizing that the 2012 yield value was from only one cage. Average litter yields inside and outside of the cages from 2008 to 2011 ranged from 0 to 425 kg ha^{-1} (Table 4.72), which were low yields. According to the rangeland health assessment protocol of Adams et al. (2005), litter yields less than 588 kg ha^{-1} in the Aspen Parkland natural sub-region with loamy soils are considered unhealthly for pastures. A litter yield greater than 1092 kg ha^{-1} reflects a healthy condition (Adams et al. 2005). This occurred inside the single cage in 2012, with a litter yield of more than 3000 kg ha^{-1} (Table 4.72). However, the benefit of increased litter likely disappeared with the continuation of grazing in 2012, as the litter yield was nearly zero outside of the cage after the 2012 grazing season.

It would appear that grazing in 2012 after only one year of rest may have negated any recovery benefits that were beginning to occur in 2011 (e.g., increased litter). The increase in pasture size and reduction in AUEs reduced the grazing pressure, but not to the point to prevent overgrazing. One year of no grazing was beneficial. However, a further reduction in herd size or a reduction in the grazing period, along with a few more years of rest, would likely be required to promote pasture recovery.

4.10.3.4 Water Flow and Quality

Water flow. Annual flow at Station 303 varied nearly 82-fold between the smallest flow in 2009 to the largest flow in 2011 (Table 4.73). As discussed in the watershed-wide assessment (Sub-section 4.4), annual flow in a given year was primarily driven by precipitation, not only by precipitation in a given year, but by precipitation the previous year. The low flow in 2009 was the result of below average precipitation in 2008 and 2009 and the high flow in 2011 was the result of above average precipitation in 2010 and 2011, which likely contributed to the relatively high flow in 2012.

Flow started in either March or April in a given year, and then generally continued to at least June (Figure 4.68). One exception was in 2009 when flow only occurred in April. In 2010, flow continued to early August, and in 2011, flow continued to early September. Also in 2010, a small amount of flow occurred in late September and into October.

Depending on the year, either snowmelt or rainfall dominated annual flow, or they roughly contributed equally (Table 4.73). In 2008 and 2012, annual flow was evenly distributed between snowmelt and rainfall runoff. In 2009, flow was almost entirely produced by snowmelt; whereas, all of the annual flow was generated by rainfall in 2010. There was lower than average winter precipitation, and greater than average rainfall in 2010. In 2011, runoff was also dominated by rainfall. On average for the 5-yr study, 46% of annual flow was caused by snowmelt and 54% was caused by rainfall.

Table 4.73. Annual flow and proportions caused by snowmelt and rainfall runoff at Station 303 at the North Pasture from 2008 to 2012.

Year	Annual flow ($m^3 yr^{-1}$)	Proportion as snowmelt (%)	Proportion as rainfall (%)
2008	89,333	50	50
2009	31,871	100	0
2010	500,222	1	99
2011	2,601,816	29	71
2012	1,045,549	48	52

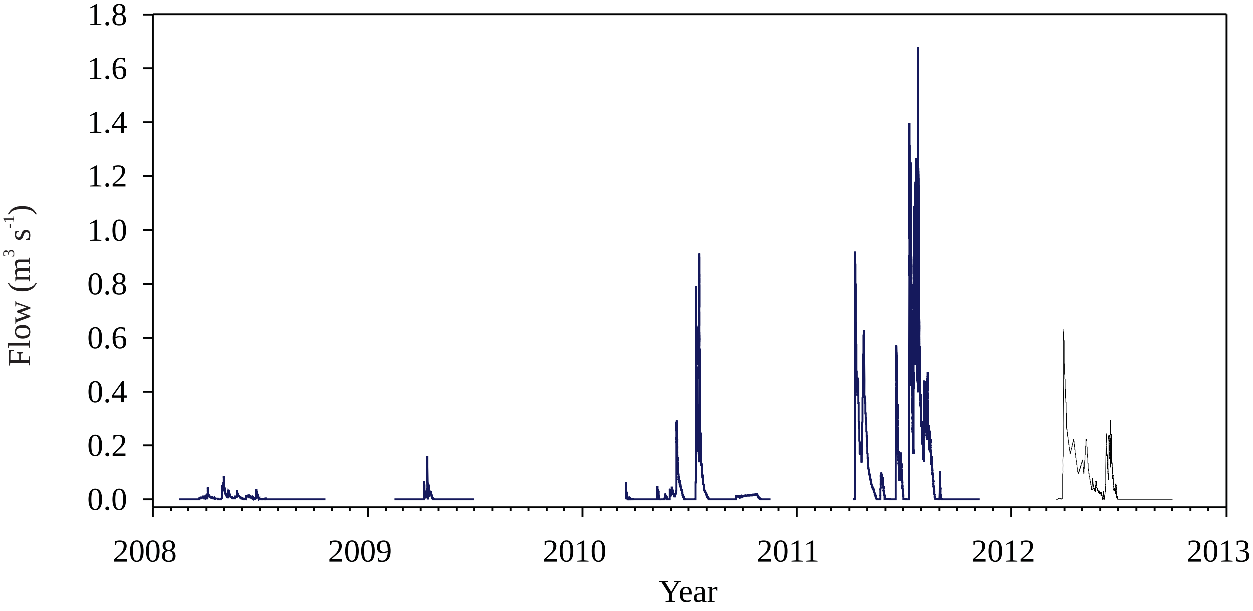

Figure 4.68. Hydrographs for Station 303 from 2008 to 2012.

The annual flow at Station 303 was determined from continuous data obtained using a Level TROLL; whereas, Station 302 was only instrumented with a staff gauge. As a result, flow could not be directly compared between the two stations, other than for the days when staff gauge readings were taken at Station 302. Stations 303 and 302 were on the mainstem of WHC. The NPS site was small and Station 302 was about 201 m downstream from Station 303. It was assumed that the annual flows were similar between the two stations and the amount of water contributed from the pasture site was relatively small. The contributing area to Station 302 was estimated at about 2350 ha. The contributing area between Station 303 and 302 was much smaller at 25 ha, which included the NPS site of 4 ha.

General water quality observations. The concentrations of the water quality parameters (all years combined) were generally similar between Stations 303 and 302 (Table 4.74 and Figures 4.69 and 4.70). During snowmelt, the concentration of TN, TP, Cl, EC, and pH at the two stations were within 5% of each other (Table 4.74). The concentration of PP and TSS was higher at Station 302;

however, values were quite small at both stations. The concentration of *E. coli* was about 60% higher at Station 303 during snowmelt. During rainfall events, there was a greater tendency of higher concentrations at the downstream Station 302, suggesting contribution to reduced water quality from Station 303 to Station 302. However, whether an increase or decrease, nearly all of the parameter concentrations between the two stations were with 15% of each other (Table 4.74). The concentrations of PP and TSS were 29 and 25% higher, respectively, at Station 302, however, concentrations were relatively small at both stations.

Table 4.74. Average water quality parameters at Stations 303 (upstream) and 302 (downstream) at the North Pasture site from 2008 to 2012.[z]

Year	n[y]	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli*	EC	pH
		($mg\ L^{-1}$)									($mpn\ 100\ mL^{-1}$)	($\mu S\ cm^{-1}$)	
						Station 303 - snowmelt							
2008	19	4.58	2.67	1.70	0.17	1.13	1.02	0.08	4	na[x]	32	622	8.00
2009	2	2.71	2.06	0.60	0.03	0.54	0.52	0.02	2	78.9	3	658	8.09
2011	6	6.83	2.19	3.74	0.85	1.30	1.22	0.08	5	33.7	140	425	7.90
2012	4	6.90	3.20	2.68	1.04	1.57	1.48	0.08	4	57.4	189	618	7.86
All	31	5.19	2.61	2.15	0.41	1.18	1.09	0.07	4	49.1	76	591	7.97
						Station 302 - snowmelt							
2008	19	4.29	2.71	1.40	0.15	1.10	0.96	0.10	6	na	8	623	8.19
2009	2	2.67	2.27	0.35	0.03	0.52	0.48	0.05	2	82.4	2	657	8.46
2011	6	6.51	2.29	3.35	0.83	1.32	1.19	0.14	14	34.8	40	420	7.94
2012	4	6.80	3.12	2.75	0.93	1.45	1.38	0.07	4	57.1	119	618	7.85
All	31	4.94	2.65	1.89	0.37	1.15	1.03	0.10	7	50.2	31	591	8.12
						Station 303 - rainfall							
2008	4	2.38	2.17	0.11	0.09	0.41	0.34	0.07	11	43.1	8	831	8.13
2010	19	2.49	2.09	0.29	0.10	1.03	0.97	0.06	4	65.5	21,164	715	8.13
2011	15	3.39	2.43	0.79	0.14	1.01	0.92	0.10	12	38.0	18,721	565	8.05
2012[w]	8	2.36	2.00	0.26	0.10	0.35	0.30	0.05	5	78.1	263	843	8.17
All	46	2.75	2.19	0.44	0.11	0.85	0.78	0.07	8	57.5	15,088	698	8.11
						Station 302 - rainfall							
2008	4	4.29	3.88	0.04	0.34	0.65	0.52	0.14	8	51.8	64	917	8.25
2010	19	2.94	2.42	0.29	0.11	1.05	0.95	0.10	15	64.0	27,510	717	8.13
2011	15	3.29	2.40	0.76	0.11	0.99	0.91	0.08	7	38.0	6,340	564	8.02
2012[w]	8	2.29	2.05	0.17	0.06	0.39	0.31	0.08	4	78.5	274	847	8.17
All	46	3.06	2.48	0.40	0.12	0.88	0.79	0.09	10	57.2	13,470	707	8.11

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] n values shown are maximums. In some cases, the n value may be less due to missing data.
[x] Chloride added late in July 2008.
[w] Two samples were collected in June 2012 after the cattle were re-introduced to this pasture and were not included in the rainfall runoff 2012 average concentrations.

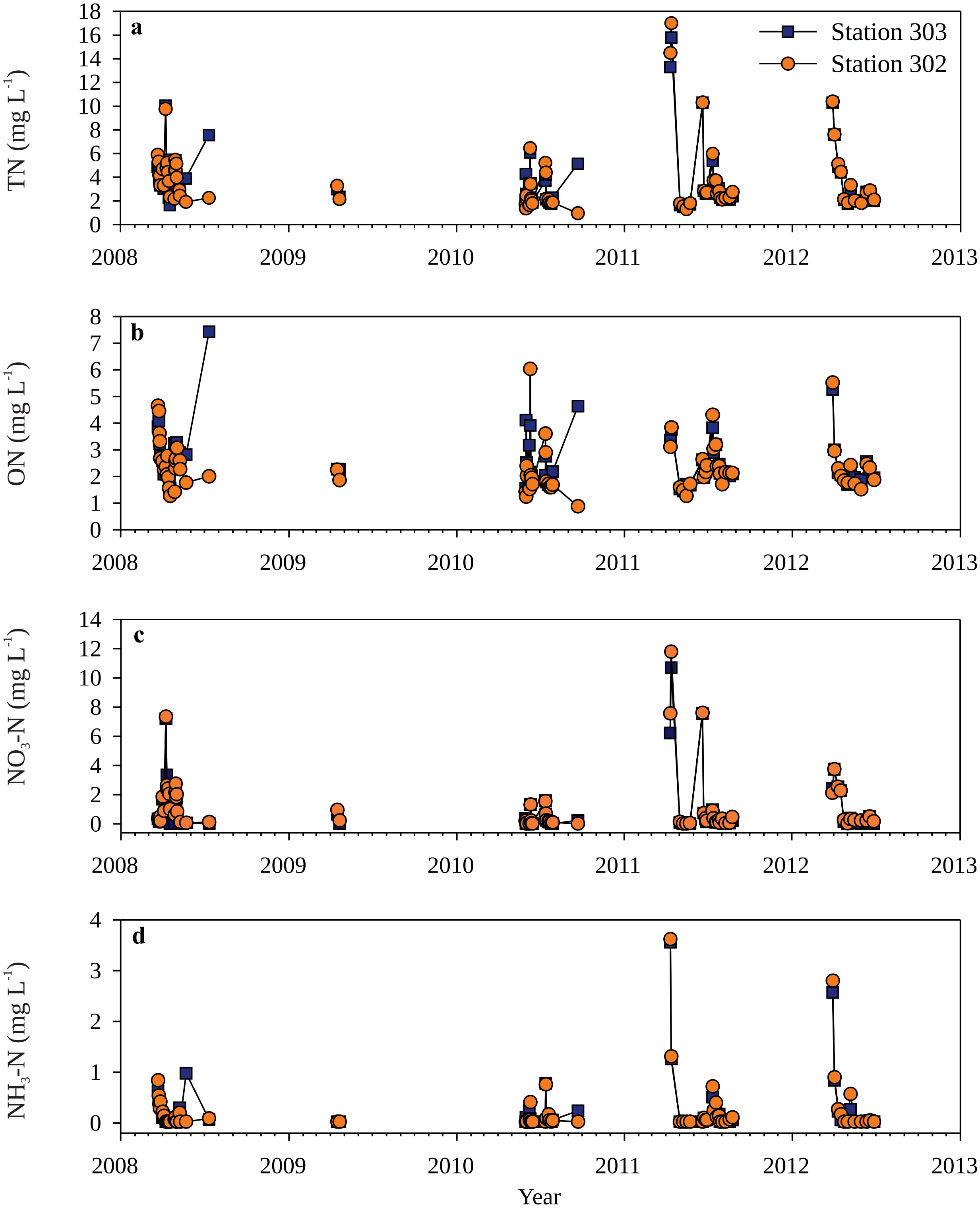

Figure 4.69. Concentrations of (a) total nitrogen (TN), (b) organic nitrogen (ON), (c) nitrate nitrogen (NO_3-N), and (d) ammonia nitrogen (NH_3-N) measured at Stations 302 (downstream) and 303 (upstream) at the North Pasture from 2008 to 2012.

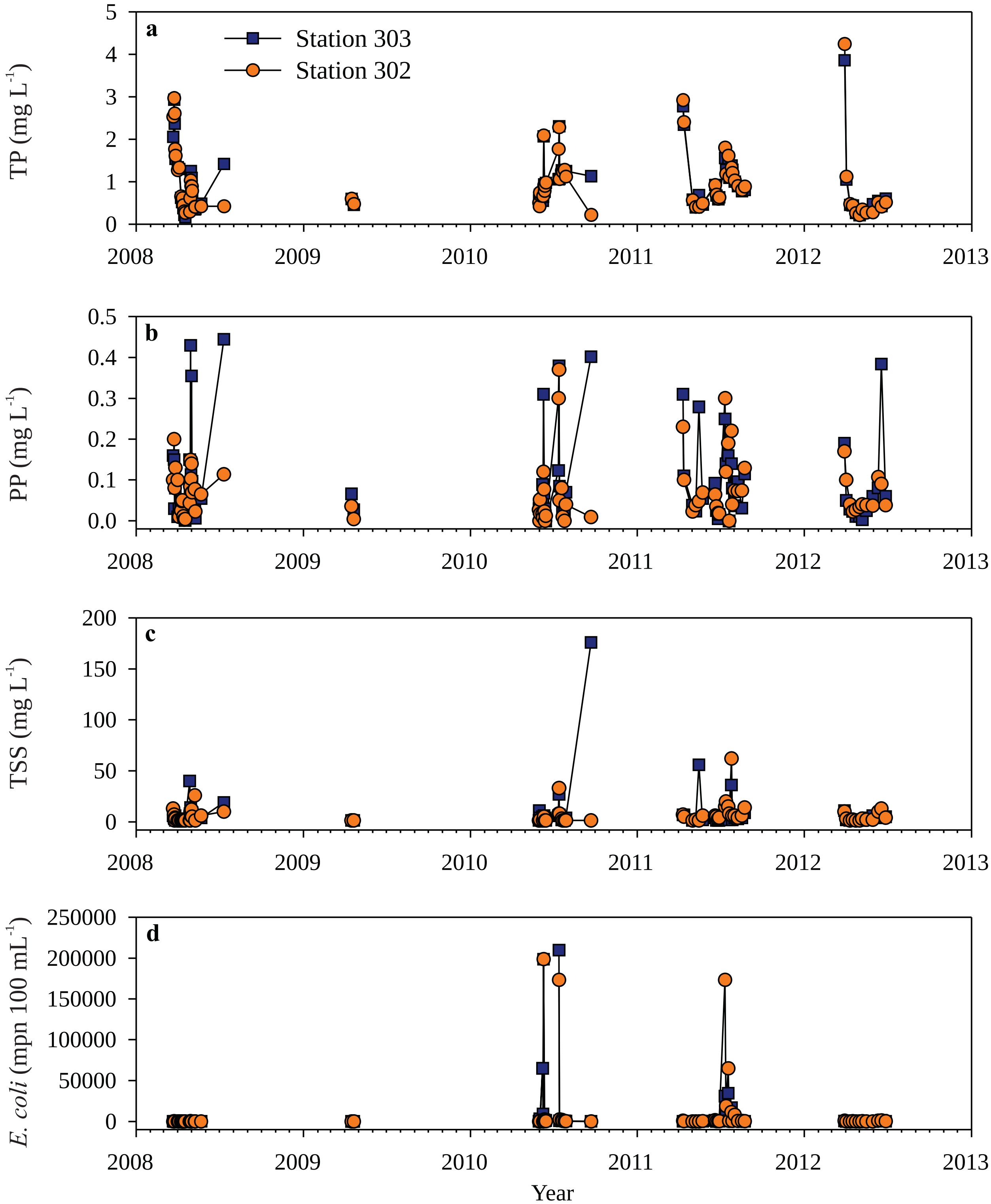

Figure 4.70. Concentrations of (a) total phosphorus (TP), (b) particulate phosphorus (PP), (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) measured at Stations 302 (downstream) and 303 (upstream) at the North Pasture from 2008 to 2012.

At both stations, the concentrations of N and P parameters were higher during snowmelt events compared to rainfall events (Table 4.74). For example, average (all years) TN concentration was 89 and 61% higher during snowmelt at Stations 303 and 302, respectively. To a lesser extent, average (all years) TP concentration was 39 and 31% higher during snowmelt at Stations 303 and 302, respectively. One exception was for PP at Station 303 where concentrations were similar between the snowmelt and rainfall. In contrast, the concentrations of TSS, Cl, *E. coli*, and EC were higher in rainfall events. The largest difference was for *E. coli*, and this likely reflected the greater microbial activity during warmer rainfall runoff compared to the colder conditions of snowmelt runoff.

Total N was dominated by ON in snowmelt and rainfall and at both stations (Table 4.74). On average (all years), TN consisted of 51 to 54% ON in snowmelt and 80 to 83% ON in rainfall. Total P was mainly in the form of TDP, with average (all years) proportions ranging from 90 to 92% among event types and stations. The high proportion of TP as TDP supports the relatively low TSS concentrations, and hence, low PP concentrations.

In some years (2008, 2001, and 2012) the concentration of TN and TP was higher early in the flow season and then decreased with time (Figures 4.69a and 4.70a). However, after an initial decrease from the start of flow until April or May in 2011 and 2012, TN and TP concentrations then increased slightly. A similar change in TN and TP concentrations with time were not as evident in 2010, and flow only occurred for a short time in 2009.

In 2008 and 2011, there were a few peak concentrations of NO_3-N (Figure 4.69c). Similar peak concentrations occurred at both stations, suggesting the source of the peak concentration originated upstream from Station 303 and the NPS site. This would also seem to be the case for NH_3-N in 2011 and 2012 (Figure 4.69d) and *E. coli* in 2010 (Figure 4.70d). The peak *E. coli* concentration at Station 302 in 2011 was difficult to explain because no cattle were present in the pasture in that year.

BMP effects on water quality. In the pre-BMP years during snowmelt, the concentrations of many water quality parameters actually decreased from upstream to downstream (Table 4.75). This suggests the NPS site did not negatively influence water quality in the mainstem during the snowmelt period. The upstream-downstream differences between pre- and post-BMP were significantly different for NO_3-N and NH_3-N during snowmelt. However, these significant differences cannot be attributed to the BMPs. In the case of NO_3-N, concentration from upstream to downstream decreased in the pre-BMP period and increased in the post-BMP period, opposite to what should have be expected for a positive BMP effect. In the case of NH_3-N, concentration decreased from upstream to downstream in the pre- and post-BMP periods. Therefore, the implemented BMPs did not have an effect on water quality during snowmelt runoff.

During the pre-BMP period for rainfall events, the concentrations of most parameters (TN, ON, NH_3-N, TP, TDP, PP, TSS, *E. coli*, and EC) were higher at the downstream station compared to upstream, suggesting the NPS site had a negative effect on water quality. For six of these parameters (TN, ON, NH_3-N, PP, TSS, and *E. coli*), concentration was lower at the downstream station compared to the upstream station in the post-BMP period. The upstream-downstream differences between pre- and post-BMP were significantly different. For the other three parameters (TP, TDP, and EC) the concentrations was similar between the two stations in the post-BMP period and the upstream-downstream differences between pre- and post-BMP were not significantly different. These results suggest the implemented BMPs had a positive effect on water quality at this site during rainfall events.

A closer examination of the individual years for the six parameters (TN, ON, NH_3-N, PP, TSS, and *E. coli*) that were significantly improved in terms water quality showed that most of the improvements occurred in 2011. In 2008 and 2010 (i.e., pre-BMP period), concentrations increased

Table 4.75. Average water quality parameter concentrations during the pre -BMP and post-BMP periods at the upstream (Station 303) and downstream (Station 302) and statistical comparisons of the concentration differences between both stations at the North Pasture. [z]

Period/Station	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl[y]	*E. coli* (mpn 100 mL^{-1})	EC (µS cm^{-1})	pH
	(mg L^{-1})											
	Snowmelt (Pre-BMP n=27, Post-BMP n=4)[x]											
Pre/Down	4.66	2.58	1.76	0.29	1.11	0.98	0.11	8	46.7	16	586	8.16
Pre/Up	4.94	2.52	2.08	0.31	1.12	1.03	0.07	4	45.0	57	587	7.98
Difference[w]	*-0.28*	*0.06*	*-0.32b*	*-0.02a*	*-0.01*	*-0.05*	*0.04*	*4*	*1.7*	*-41*	*1*	*0.18*
Post/Down	6.80	3.12	2.75	0.93	1.45	1.38	0.07	4	57.1	119	618	7.85
Post/Up	6.90	3.20	2.68	1.04	1.57	1.48	0.08	4	57.4	189	618	7.86
Difference	*-0.10*	*-0.08*	*0.07a*	*-0.11b*	*-0.12*	*-0.10*	*-0.01*	*0*	*-0.3*	*-70*	*0*	*-0.01*
	Rainfall (Pre-BMP n=24, Post-BMP n=20) [x,v]											
Pre/Down	3.11	2.64	0.23	0.14	0.96	0.86	0.10	13	62.1	22,527	752	8.16
Pre/Up	2.44	2.09	0.25	0.09	0.90	0.84	0.07	6	63.1	17,327	735	8.14
Difference	*0.67a*	*0.55a*	*-0.02*	*0.05a*	*0.06*	*0.02*	*0.03a*	*7a*	*-1.0b*	*5200a*	*17*	*0.02a*
Post/Down	3.06	2.32	0.61	0.10	0.83	0.76	0.07	6	50.4	4769	642	8.04
Post/Up	3.15	2.33	0.66	0.14	0.83	0.75	0.08	10	50.2	14,078	641	8.08
Difference	*-0.09b*	*-0.01b*	*-0.05*	*-0.04b*	*0*	*0.01*	*-0.01b*	*-4b*	*0.2a*	*-9309b*	*1*	*-0.04b*
	Overall (Pre-BMP n=51, Post-BMP n=24) [x,v]											
Pre/Down	3.93	2.61	1.06	0.22	1.04	0.92	0.10	10	57.7	10,782	664	8.16
Pre/Up	3.76	2.32	1.23	0.21	1.02	0.94	0.07	5	57.9	8317	657	8.05
Difference	*0.17*	*0.29a*	*-0.17b*	*0.01a*	*0.02*	*-0.02*	*0.03a*	*5a*	*-0.02*	*2465a*	*7*	*0.11a*
Post/Down	3.68	2.45	0.97	0.24	0.93	0.86	0.07	6	51.5	3994	638	8.01
Post/Up	3.77	2.47	1.00	0.29	0.95	0.87	0.08	9	51.4	11,763	637	8.04
Difference	*-0.09*	*-0.02b*	*-0.03a*	*-0.05b*	*-0.02*	*-0.01*	*-0.01b*	*-3b*	*0.01*	*-7769b*	*1*	*-0.03b*

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

[y] Chloride was added late July 2008. The pre-BMP period n values are 8 for snowmelt, 20 for rainfall, and 28 for all samples.

[x] n values shown are maximums. In some cases, the n value may be less due to missing data.

[w] Average differences with different letters per event and parameter indicate a significant BMP phase difference at $P <$ 0.1.

[v] Two samples were collected in late June 2012 after the cattle were re-introduced to this pasture were not included in the post-BMP rainfall runoff and overall average concentration comparisons.

from upstream to downstream for rainfall events (Table 4.74); whereas, the opposite was true in 2011. In 2012, half the parameters (TN, NH_3-N, and TSS) decreased from upstream to downstream and half the parameters (ON, PP, and *E. coli*) increased from upstream to downstream (Table 4.74). Therefore, the positive BMP effect was due to the exclusion of the livestock from the site in 2011. The successful establisment of the bioengineering may have also provided some contribution to the measured water quality improvement. Combining the snowmelt and rainfall data showed similar results as for rainfall, except the upstream-downstream differences between pre- and post-BMP were not significantly different for TN (Table 4.75). We anticipate that if overgrazing continues, the water quality improvements observed in 2011 will be reversed. A reduction in herd size, a reduction in the grazing period, more years of resting the pasture, or a combination of these three BMPs, would likely be required in order to maintain water quality improvement effects, as well as improved pasture health.

4.10.4 Conclusions

- The BMP plan was successfully implemented at this site, and the plan included a doubling of the pasture size; excluding cattle from a short reach of the creek, bioengineering of the excluded area; reduced stocking rate; and resting the pasture from grazing for one year, along with weed control. The cost of implementing the BMP plan was less than $475.
- The various components of the BMP plan were implemented from 2009 to 2011. For the purpose of assessing BMP effects on water quality, the pre-BMP period was from 2008 to May 2010, and the post-BMP period was from June 2010 to 2012.
- The bioengineering of the excluded area established very well within 3 yr and provided excellent cover and stability to the eroded area along WHC.
- Soil N and P fertility for optimum forage growth were low at this site. Fertilizer was routinely applied to the site, but the target nutrient levels are not necessarily met each year.
- Production cage data supported that the NPS site was overgrazed, with low grass, forb, and litter yields following a season of grazing. Low litter yields suggest unhealthy pasture conditions. One year of no grazing resulted in a healthy accumulation of litter. However, the resumption of grazing reversed this improvement in litter quality.
- It was estimated that the pasture size of 9 ha (Pasture A plus B) would need to be at least three- to five-fold larger to avoid exceeding carrying capacity of the pasture for the same number and type of livestock. This estimate assumed fair pasture conditions. Therefore, the increase in pasture size from 4 to 9 ha likely had little benefit because overgrazing conditions continued.
- Annual flow in the mainstem through the site ranged from 0.03 to 2.6 million m^3 yr^{-1}. The magnitude of annual flow was largely driven by precipitation.
- On average for the 5-yr study, 46% of annual flow was caused by snowmelt and 54% was caused by rainfall. However, in some years, all flow was either generated only by snowmelt or rainfall.
- The creek through the site was ephemeral, and flow typically started in March or April and stopped in late spring or in the summer. The latest flow occurred in October in one year.

- The concentrations of water quality parameters were similar between the two monitoring stations, particularly during snowmelt. During rainfall events, there was a greater tendency of higher concentration at the downstream, suggesting contribution to reduced water quality from upstream to downstream at this site.
- The concentrations of N and P parameters were higher during snowmelt events; whereas, the concentrations of TSS, Cl, *E. coli*, and EC were higher in rainfall events.
- On average, TN consisted of 51 to 54% ON in snowmelt and 80 to 83% ON in rainfall, and TP consisted of 90 to 92% TDP.
- Resting the pasture from grazing for one year (2011) resulted in significant improvement in water quality including the concentrations of TN, ON, NH_3-N, PP, TSS, and *E. coli*. for rainfall events during the rest year. The resumption of grazing in 2012 reduced the amount of water quality improvement and likely will be negated if past grazing practices are continued.
- A reduction in herd size, a reduction in the grazing period, more years of resting the pasture, or a combination of these three BMPs, would likely be required in order to maintain water quality improvement effects, as well as improved pasture health.

4.11 South Pasture Site

4.11.1 Introduction and Hypothesis

The SPS site was the second pasture site in the WHC Sub-watershed, and was added to the study in 2008. High livestock stocking rates and visual assessments indicated that this site was overgrazed. The BMPs, which were implemented in 2010, focused on livestock management using fencing and an extended watering system, without a reduction in stocking rates. The BMP plan included switching from continuous grazing to rotational grazing to control cattle distribution. This BMP plan was designed to improve forage utilization, improve pasture health, and with better pasture health, improve water quality in runoff from the pasture. One edge-of-field monitoring station was used to assess water quality runoff at this site. In addition, the effects of grazing management were evaluated by measuring forage production.

The assumption underlying the choice of BMPs was that poor pasture quality, caused by overgrazing, increased the contribution of dissolved nutrients and bacteria to runoff during snowmelt and rainfall runoff at this site. The hypothesis was:

- The implementation of a rotational grazing BMP will improve pasture quality and have a positive effect on water quality in runoff from this site. It is anticipated that dissolved nutrients will respond more than particulate nutrients.

4.11.2 Methods

4.11.2.1 Site Description and Management

The SPS site was located in the southern part of the sub-watershed (Figure 4.3). The size of the pasture was about 39 ha (Figure 4.71). A water trough was in the northeast part of the pasture in a corral adjacent to the farmyard (Figure 4.71). A runoff-fed dugout existed in the north part of the pasture, but was often fenced off as it was not a reliable water source. Surface hydrology in the pasture was defined by two drainage channels. Both channels flowed from west to east; however, the southern channel was more defined and flows were greater. Both channels converge in the wooded area east of the pasture (Figure 4.71) and then flowed south to a wetland.

Soils at the SPS site were dominated by Orthic Black Chernozems (40%), Eluviated Black Chernozems (40%), and Orthic Humic Gleysol (20%). This soil type is typical in the WHC Sub-watershed and the region. The SPS site was in the same AGRASID soil landscape model (CYLP2/U1hc) as described for a portion of the NFD (Alberta Soil Information Centre 2013) (Sub-section 4.7.2.1). The surface soil at the site had a loam texture (38% sand, 20% clay), a pH of 6.5, electrical conductivity of 0.6 dS m^{-1}, 4270 mg kg^{-1} TN, 660 mg kg^{-1} TP, and 9.6% organic matter (Appendix 4).

At the time of the study, the vegetation at the SPS site was defined as tame forage using the definition in Adams et al. (2005), as the area had ≥ 50% cover of introduced species. It was dominated by introduced vegetative species such as brome grass (*Bromus*), clover (*Trifolium*), Kentucky bluegrass (*Poa pratensis*), red fescue (*Festuca rubra*), and dandelion. Historically, the area would have been occupied by trees and shrubs as indicated by the tree stands adjacent to the pasture and throughout the sub-watershed. Although this site had been in pasture for a number of years, it was evident that at some point the pasture was tilled. Aerial photography showed signs of furrows, which were seen late in the year when vegetation was grazed. Cattle trails generally followed these furrows.

The SPS site was used as a seasonal pasture with no defined management plan other than the availability of forage. Prior to and during the study, the landowner rented the pasture for grazing by cattle. Depending on forage availability, grazing started from early to mid-June and ended in late October to early November. The number of animals in the pasture were 26, 31, 36, 31, and 31 cow-calf pairs and one 1 bull from 2008 to 2012, respectively (Table 4.76). From 2008 to 2010, after

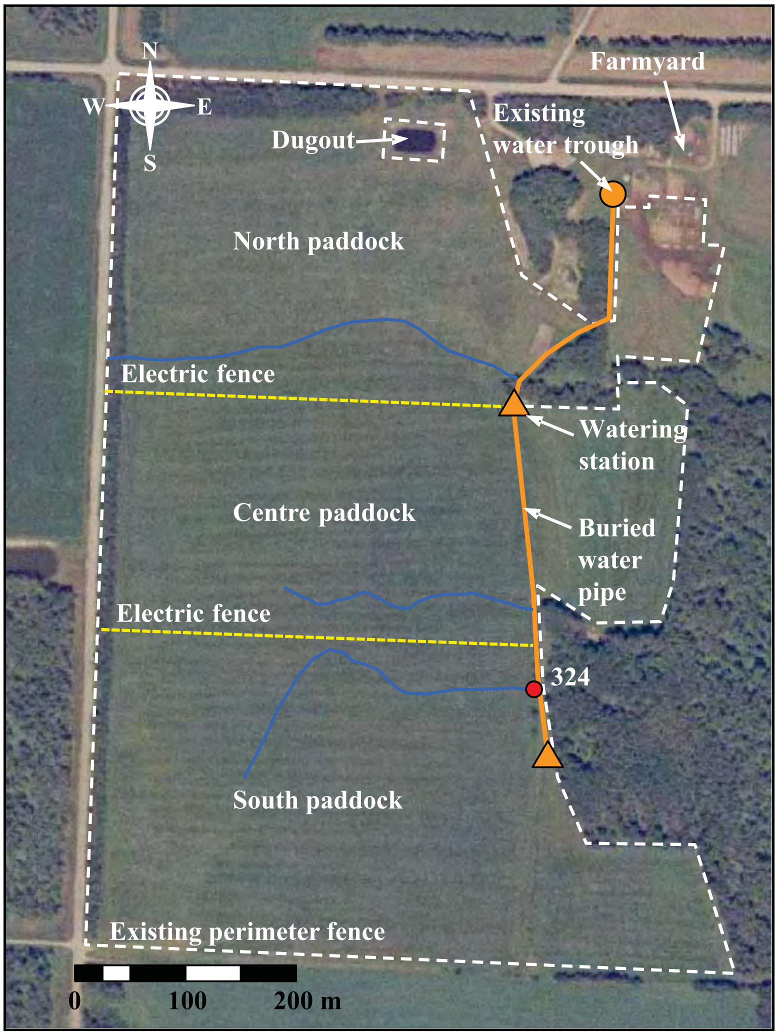

Figure 4.71. The South Pasture showing the electric fence and watering system installed in 2010, and the water monitoring Station 324.

being moved from the pasture, the cattle were allowed to graze in the bush and on cultivated land east of the pasture late in the fall as part of a larger herd. During grazing in the late fall, cattle still had access to a small area in the northeast corner of the SPS site where the water trough was located by the corrals.

Table 4.76. The grazing management used for cow-calf pairs (cc) and one bull (b) at the South Pasture site from 2008 to 2009 (pre-BMP period) and from 2010 to 2012 (post-BMP period).

Period	Paddock	Days in paddock	Stocking rate[z] AUM ha^{-1}
2008 (26 cc, 1 b)			
June 11 to Oct 26	All	137	4.5
2009 (31 cc, 1 b)			
June 15 to Oct 16	All	123	4.8
2010 (36 cc, 1 b)[y]		140	6.2
June 12 to 24	North	12	
June 24 to July 8	Centre	14	
July 8 to 26	South	18	
July 26 to Aug 6	North	11	
August 6 to 19	Centre	13	
Aug 19 to Sept 2	South	14	
Sept 2 to 16	North	14	
Sept 16 to 30	Centre	14	
Sept 30 to Oct 26	South	26	
Oct 26 to 30	All	4	
2011 (31 cc, 1 b)[x]		159	6.0
June 5 to 27	Centre	22	
June 27 to July 13	South	16	
July 13 to 20[w]	Centre and South	7	
July 20 to Aug 9	North	20	
Aug 9 to 29	Centre	20	
Aug 29 to Sept 26	South	28	
Sept 26 to Oct 10	North	14	
Oct 10 to Nov 11	All	32	
2012 (31 cc, 1 b)		139	5.4
June 12 to July 4	South	22	
July 4 to 25	Centre	21	
July 25 to Aug 15	North	21	
Aug 15 to 29	South	14	
Aug 29 to Sep 12	Centre	14	
Sept 12 to 26	North	14	
Sept 26 to Oct 10	South	14	
Oct 10 to 29	All	19	

[z] AUM ha^{-1}= Animal unit month per hectare. It was assumed the average weight per cow was 680 kg. A cow of this size has an animal unit equivalent value of 1.5 (Kaulbars 2009). AUM ha^{-1} = number of cow-calf pairs × AUE × number of months in pasture ÷ hectares.
[y] Bull was added on June 19.
[x] Bull was added on June 27.
[w] Cattle broke the fence and were in the Centre and South paddocks.

The pasture was considered overgrazed (Figure 4.72). Repeated seasonal use and overgrazing resulted in limited plant diversity and structure in the pasture, which, under prolonged adverse condition such as drought, could lead to erosion and reduced forage production.

4.11.2.2 Implementation of Beneficial Management Practices

The BMP plan was developed with assistance from the Rocky Mountain Forage Association. Reducing the stocking rate or resting the pasture for one or more seasons was not an option at this site. With this limitation, a plan was developed to introduce rotational grazing. On May 12, 2010, the pasture was divided into three paddocks (Figure 4.71) using electric fences (Figure 4.73). The electric fences consisted of 1.8-m long heavy duty steel T-posts spaced every 30 m supporting the wire. The producer's existing electric fence system supplied electricity to the fences. The size of the paddocks were 13 ha (north), 12 ha (centre), and 14 ha (south). In May and June 2010, a watering system was installed to supply water to the paddocks. About 600 m of 7-cm diameter plastic pipe were trenched (10 to 20 deep) into the soil from the water source in the farmyard to the paddocks (Figures 4.71 and 4.72b). Two water troughs were installed: one to supply water to the north and centre paddocks and one to supply water to the south paddock (Figures 4.71 and 4.73c). Barriers were constructed to protect the troughs from damage by the cattle. After each grazing season and prior to freezing, the buried pipeline was drained and cleared of water using forced air.

In 2010, the rotational grazing plan was initiated and the cattle were moved among the three paddocks during the grazing season (Table 4.76). The number of cattle placed in the pasture ranged from 31 to 36 cow-calf pairs from 2010 to 2012. The length of time cattle were allowed to graze in

Figure 4.72. Early spring conditions (April 17, 2008) of the South Pasture showing minimal forage as evidence of overgrazing.

a given paddock ranged from 7 to 28 d. Each paddock was visited two to three times by the herd during each grazing season. At the end of the each rotational grazing period, the herd was allowed simultaneous access to all three paddocks ranging from 4 to 32 d, depending on forage availability.

4.11.2.3 Soil Sampling

Soil characterization samples (Sub-section 2.9) were collected on October 22, 2009. Other soil samples collected at this site included 0- to 15-cm agronomic samples in fall 2008 and 0- to 60-cm soil-test samples in fall 2011. The agronomic and soil-test samples were collected from eight sampling points using a 200-m grid pattern. Soil sampling was carried out in accordance to the general methodology described in Sub-section 2.9.

4.11.2.4 Rangeland Production

Ten production cages were initially placed at the SPS site in 2008. The cages were placed throughout the pasture to obtain a representative forage yield (Figure 4.74). When the pasture was separated into three paddocks in 2010, the number of cages was reduced to nine and three cages

Figure 4.73. At the South Pasture, (a) electric fences was used to divide the pasture into paddocks and a (b) underground water pipeline and (c) water troughs were installed to supply water to the paddocks. Images taken on September 16 (top) and June 3 (bottom), 2010.

were placed in each paddock. Grass, forb, and litter samples were taken from inside the cages, as well as from a representative area outside the cages. Further details of vegetation and litter sampling are in Sub-section 2.12.2.

Average yields were calculated for grass, litter, and forbs for each pre- and post-BMP year. In some years, production cages were knocked down by livestock and these were not included in the calculations. A single population of average yield differences for each year was created for each biomass type (grass, forb, and litter) by subtracting the outside cage yield from the inside cage yield. These differences were used for statistical comparisons between years rather than the inside-cage and/or outside-cage data. Further details are in Sub-section 2.12.2.

4.11.2.5 Water Flow and Quality

One edge-of-field water monitoring station (Station 324) was used at the SPS site. The monitoring station was placed at the exit point from the pasture on the south drainage channel (Figure 4.71). Grab samples were taken in 2008 and in 2009, Station 324 was instrumented with a circular flume and an automatic Isco water sampler (Sub-sections 2.6, 2.7, and 2.8).

Statistical analysis and load calculations are described in Sub-section 2.8.4. No pre-BMP rainfall runoff samples were collected at this site, and as a result, the pre-BMP versus post-BMP statistical tests were completed on only the snowmelt runoff samples. The BMP grazing rotation started in June 2010, which was after the snowmelt period in 2010. Therefore, the pre-BMP snowmelt samples were from 2008 to 2010 and the post-BMP snowmelt samples were from 2011 to 2012.

Figure 4.74. A production cage at the South Pasture prior to vegetation clipping in October 2012.

4.11.3 Results and Discussion

4.11.3.1 Implementation of Beneficial Management Practices

The BMP plan was successfully implemented in 2010 with the application of rotational grazing among three paddocks established in the pasture. The grazing plan from 2010 to 2012 worked very well. The producer was pleased with the BMP, including the watering system, and the electric fences required minimum maintenance. The design used was a simple rotational grazing plan, which required a moderate level of management (Kaulbars 2009). Some advantages of a simple rotational grazing plan include (1) more control with timing and intensity of grazing, (2) provide more even grazing, (3) may improve pasture condition compared to continuous grazing, (4) allows pastures to rest and plants to recover, and (5) improve distribution of manure (Kaulbars 2009). However, based on visual observations, noticeable improvement of pasture quality was not evident (Figure 4.75).

In spite of the adoption of rotational grazing, the key element of overstocking was not addressed. In fact, during the BMP period (2010 to 2012), the herd size was either larger or equal to the pre-BMP period (Table 4.76). Plus, the cattle were in the pasture for a longer period of time in the post-BMP period (139 to 159 d yr^{-1}) compared to the pre-BMP period (123 and 137 d yr^{-1}). Both these factors increased the grazing pressure on the site in the post-BMP period. The stocking rate in 2008 and 2009 were 4.5 and 4.8 AUM ha^{-1}; whereas, from 2010 to 2012, the annual stocking rate ranged from 5.4 to 6.2 AUM ha^{-1}. Even though the number of cattle in 2011 and 2012 were the same as in 2009, the cattle were in the pasture for longer periods during the former two years (Table 4.76).

Kaulbars (2009) suggests that the carrying capacity of a pasture in poor condition that receives 350 to 450 mm yr^{-1} of precipitation, which includes the average precipitation for the Whelp Creek Sub-watershed, is 1 AUM ha^{-1}. A pasture in fair condition has a carrying capacity of 1.5 AUM ha^{-1}, and a pasture in excellent condition has a carrying capacity of 3 AUM ha^{-1}. During the 5-yr study,

Figure 4.75. Conditions of the South Pasture on (a) April 7, 2008 (pre-BMP) and (b) March 31, 2012 (post-BMP).

the average herd size was 31 cow-calf pairs and they spent an average of 140 d at the SPS site (39 ha in size). Using these average values, the number of animals for a fixed grazing period of 140 d and the length of grazing period for a fix herd size of 31 cow-calf pairs were calculated for different pasture conditions (Table 4.77). The calculations showed that even if the pasture was in excellent condition the herd size or the grazing period should be reduced by about 50%, or some combination thereof, so not to exceed the carrying capacity of the pasture (Table 4.77). Under poor or fair conditions, even greater reductions would be required, and this is likely the case for the SPS site. At the SPS site, any benefit from the rotational grazing BMP was likely negated by the continued and enhanced overstocking. Another BMP option would be to rest the pasture for one or more seasons.

The total cost of BMP implementation was just over $3300.00, with 44 h of labour (Table 4.78). The largest cost was the installation of the waterline, followed by the watering stations.

4.11.3.2 Soil

The concentrations of extractable NO_3-N were very low in the agronomic (0 to 15 cm) and soil-test (0 to 60 cm) samples (Table 4.79). The concentration of STP was moderately low to adequate in the surface soil. The STP in the surface soil may be due to the manure distribution on the soil surface from overstocked conditions in the pasture. In the soil-test samples, the concentration of NO_3-N was consistent with soil depth and the concentrations of NH_4-N and STP decreased with

Table 4.77. Estimated number of animals or length of grazing period to meet the carrying pasture for a 39-ha pasture in the Whelp Creek Sub-watershed.

Pasture condition	Carrying capacity[z] (AUM ha^{-1})	Number of animals when grazing period is held at 140 d[y]	Days of grazing when number of livestock is held at 31 cow-calf pairs[y]
Poor	1.0	5 to 6	26
Fair	1.5	8 to 9	38
Good	2.0	11	51
Excellent	3.0	17	77

[z] From Kaulbars (2009).
[y] Pasture area = 39 ha, 1 mo = 30.5 d, and AUE per cow-calf pair = 1.5 (Kaulbars 2009), AUM ha^{-1} = number of cow-calf pairs × AUE × number of months in pasture ÷ hectares.

Table 4.78. Cost of beneficial management practices at the South Pasture site from 2010 to 2012.

Item	Cost ($)	Labour (h)
Paddocks establishment (electric fence)[z]	549	14
Watering stations[z]	739	8
Waterline installation[z]	1932	14
Waterline winterizing	120	8
Total	**3340**	**44**

[z] 5% miscellaneous was added to account for nails, screws, and other small construction items.

Table 4.79. Concentrations for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) for agronomic and soil-test samples collected in the fall at the South Pasture.

Year	Soil layer (cm)	NO_3-N	NH_4-N	STP
		----------	(mg kg^{-1})	----------
			Agronomic samples	
2008[z]	0-15	3.0	7.4	62.5
			Soil-test samples	
2011[y]	0-15	1.0	4.7	39.9
	15-30	1.0	3.3	4.2
	30-60	1.0	2.5	2.3

[z] Average of five samples (n = 5).
[y] Each layer was a composite sample prepared from eight sampling points.

depth. In terms of nutrient requirements for optimum forage growth in the Black Soil Zone, fertilizer is recommended for this site. Based on McKenzie (2005), the soil-test NO_3-N and STP results suggest that about 134 kg ha^{-1} N and 5 kg ha^{-1} P would be required for optimum forage at this site. Fertilizer has not been applied to the SPS site. In addition to reducing the herd size and/or reducing the length of the annual grazing period, the application of fertilizer to the SPS site may help pasture recovery. This would be of minimal risk to water quality as nutrients are low at this site. Weed control would also be beneficial at this site.

4.11.3.3 Rangeland Production

The average grass, forb, and litter yields inside the production cages were smallest in 2010 and 2011 (Table 4.80). Yields were highest in 2012 and intermediate in 2008 and 2009. Outside the cages, yields were lowest in 2009 or 2010. Caution must be taken with the 2012 data, as five out of nine cages were knocked over prior to harvest and were not sampled. The lowest inside-cage yields in 2010 may have been the result of the preceding by two years, which had less than average precipitation (Sub-section 4.2.2).

According to Adam et al. (2005), a litter yield greater than 1092 kg ha^{-1} is considered healthy, 588 to 1092 kg ha^{-1} is considered healthy with problems, and less than 588 kg ha^{-1} is considered unhealthy for a pasture in the Parkland Natural Region on loamy soil. Average litter yield inside the cages were in the healthy with problems category for all five years. This was also the case for outside the cages in 2008 and 2012. However, in 2009, 2010, and 2011, the litter yield outside the cages was in the unhealthy category.

On average, the grass yield inside the cage in the pre-BMP period (3225 kg ha^{-1}) was similar to grass yield in the post-BMP period (3120 kg ha^{-1}) (Table 4.80). This was also true for the average yields outside the cage between the two periods. Forb and litter yields tended to be less during the post-BMP period compared to the pre-BMP period. The differences between inside and outside the

Table 4.80. Cage harvest results of average dry weight in kg ha^{-1} for grass, forbs, and litter at the South Pasture from 2008 to 2012.

		Pre-BMP period		Post-BMP period		
		2008 (n = 10)	2009 (n = 8)	2010 (n = 8)	2011 (n = 7)	2012 (n = 5)
Grass	Inside cage	3396	3054	2496	2621	4243
	Outside cage	1678	340	494	1129	1114
	Difference[z]	*1718b*	*2714a*	*2002ab*	*1492b*	*3129a*
Forb	Inside cage	246	265	82	192	308
	Outside cage	161	25	0	104	185
	Difference[z]	*85a*	*240a*	*82a*	*89a*	*123a*
Litter	Inside cage	745	747	353	549	969
	Outside cage	769	286	61	341	786
	Difference[z]	*-24a*	*461a*	*291a*	*208a*	*183a*

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

cages for grass yield in 2009 and 2012 were significantly higher than in 2008 and 2011 (Table 4.80). Significantly smaller inside-outside differences in the post-BMP period compared to the pre-BMP period would indicate improved pasture conditions after a grazing season. In terms of the pre- versus post-BMP periods, the grass yield differences were inconclusive regarding a BMP effect. There were no significant differences among years for the inside-outside cage differences for forb or litter yields. Overall, these results suggest that no improvement in pasture conditions occurred as the result of the rotational grazing BMP. As discussed above, it is likely that the continued overstocking of this pasture resulted in no improvement in pasture quality despite the adopted rotational grazing.

4.11.3.4 Water Flow and Quality

Water flow. Flow at the edge-of-field Station 324 was generated only by snowmelt in four out of the five years (Table 4.81). In 2011, the majority of flow was caused by rainfall runoff, which occurred in July and August (Figure 4.76). The largest annual flow was in 2011, which was consistent with other monitoring stations in the sub-watershed. Snowmelt occurred in March and/or April and the melt periods spanned from 5 d in 2012 to 20 d in 2011 (Figure 4.76). The rainfall runoff events in 2011 spanned from 9 d in July to 13 d in August. No flow was recorded in 2008; however, runoff was observed from April 3 to 28. Little overland flow was observed at the site in 2009 and 2010, and the majority of flow observed in these years was from snowmelt in the main channel near Station 324 (Figure 4.77).

Table 4.81. Annual flow and percent contribution by snowmelt and rainfall runoff at the South Pasture from 2008 to 2012.

Year	Annual flow (m^3 yr^{-1})	Proportion as snowmelt (%)	Proportion as rainfall (%)
2008	na[z]	100	0
2009	677	100	0
2010	521	100	0
2011	9459	37	63
2012	3214	100	0

[z] na = not available as the site was not instrumented for continuous flow measurement.

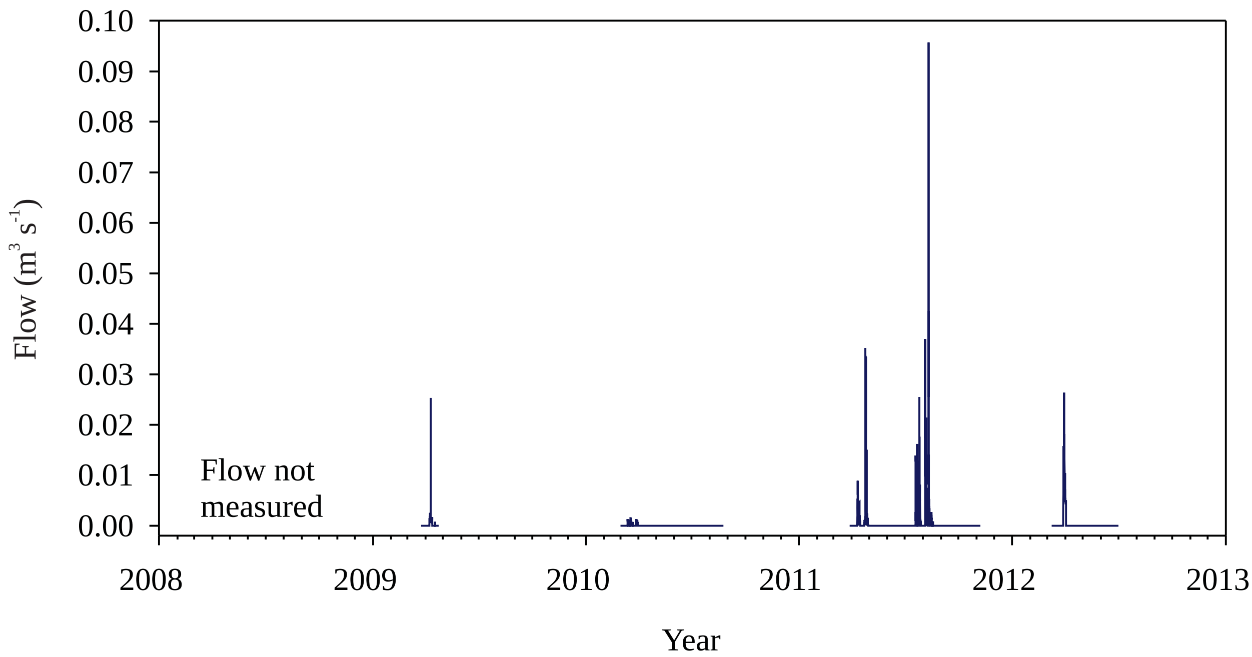

Figure 4.76. Hydrograph for the edge-of-field Station 324 at the South Pasture site from 2008 to 2012.

Figure 4.77. Snowmelt conditions in the main channel near the edge-of-field Station 324 on March 18, 2010.

General water quality observations. On average (all years) for snowmelt runoff, 73% of the TN was in ON form. In rainfall runoff in 2011, nearly all of the TN (98%) was in ON form (Table 4.82). Total P was mainly in the form of TDP for snowmelt runoff (94%) and rainfall runoff (91%).

In 2011, the only year with recorded rainfall runoff, the concentrations of TN, ON, PP, TSS, *E. coli*, and EC were higher in rainfall runoff than in snowmelt runoff (Table 4.82). Conversely, the concentrations of NO_3-N, NH_3-N, TP, and TDP were higher in snowmelt in 2011. Compared to the overall averages (all years) for snowmelt runoff, the concentrations of most parameters were higher in snowmelt runoff then in rainfall runoff, including TN, NO_3-N, NH_3-N, TP, TDP, PP, TSS, and Cl.

There was no consistent year effect on average concentrations in snowmelt runoff. The highest average concentration of several parameters (TN, NH_3-N, TP, TDP, Cl, and *E. coli*) occurred in 2009 (Table 4.82). The lowest average concentration occurred in either 2010 or 2011 for most parameters, except for NO_3-N and *E. coli*. Generally, average concentrations in snowmelt did not vary greatly from year to year (Table 4.82 and Figure 4.78). Within a given year, there were some differences in how parameter concentration changed with time. In 2009, 2010, and 2012, the highest concentration of nearly all parameters was measured in the first water sample, after which, with some variation, concentration decreased with time during the snowmelt season (Figure 4.78). It is often typical to observe high concentration in the initial runoff flush followed by lower concentrations. However, similar change in concentration with time was not as consistent in 2011, except for ON, TP, and TDP, and was not observed at all in 2008. In fact, in 2008, all N parameters and TSS showed a strong increase in concentration with time during snowmelt.

Total suspended solids concentrations were generally quite low, remaining less than 20 mg L^{-1} throughout the study, with the exception of four peaks: on April 10, 2008, April 28, 2008, April 10, 2009, and July 22, 2011 (Figure 4.78c). Average Cl concentration was relatively stable from 2008 to 2011, and then increased in 2012 (Table 4.82). The concentration of *E. coli* was highest during rainfall runoff in late July 2011, with the highest concentration of 21,420 mpn 100 mL^{-1} on July 26 (Figure 4.78d).

Annual nutrient and sediment loads were lowest in 2010, except for NO_3-N, which had the lowest load in 2012 (Table 4.83). The smallest annual flow also occurred in 2010 (Table 4.81). The highest annual loads for most parameters occurred in 2011, which also had the highest annual flow. The exception was for NH_3-N, which had higher loads in 2008 and 2012 than in 2011. The reason for this is the average concentration of NH_3-N in 2011 (snowmelt and rainfall runoff) was much lower compared to the other years (Table 4.82).

BMP effects on water quality. The average concentration of most of the parameters was less during the post-BMP period compared to the pre-BMP period (Table 4.84). However, the only statistically significant decrease in concentration from pre- to post-BMP was for NH_3-N. In contrast, the average concentration for Cl and EC were significantly higher in the post-BMP period. The concentration of NO_3-N was also higher in the post-BMP period, but was not significantly different from the pre-BMP period.

Table 4.82. Average runoff water quality parameters measured at Station 324 at the South Pasture site from 2008 to 2012.[z]

Year (period)	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli* (mpn 100 mL^{-1})	EC ($\mu S\ cm^{-1}$)	pH
		---- (mg L^{-1}) ----											
						Snowmelt							
2008 (pre-BMP)	6	2.65	2.07	0.27	0.28	1.59	1.46	0.13	27	na[y]	56	156	7.52
2009 (pre-BMP)	5	3.01	1.94	0.29	0.75	2.16	2.09	0.07	16	4.82	331[x]	125	7.75
2010 (pre-BMP)	8	1.92	1.22	0.30	0.37	1.34	1.26	0.08	5	2.93	272	76	7.32
2011 (post-BMP)	11	1.75	1.20	0.48	0.07	1.43	1.38	0.05	5	3.15	58	152	7.58
2012 (post-BMP)	5	2.71	2.51	0.04	0.17	1.83	1.71	0.12	10	12.0	117	216	7.48
All	35	2.26	1.65	0.31	0.29	1.60	1.51	0.08	11	4.90	149	140	7.52
						Rainfall							
2011 (post-BMP)	8	1.83	1.79	0.03	0.03	0.75	0.68	0.07	9	4.23	4194	358	7.94

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

[y] Chloride was added in late July 2008.

[x] Because of a missing value for the April 17 sample, n = 4 instead of 5.

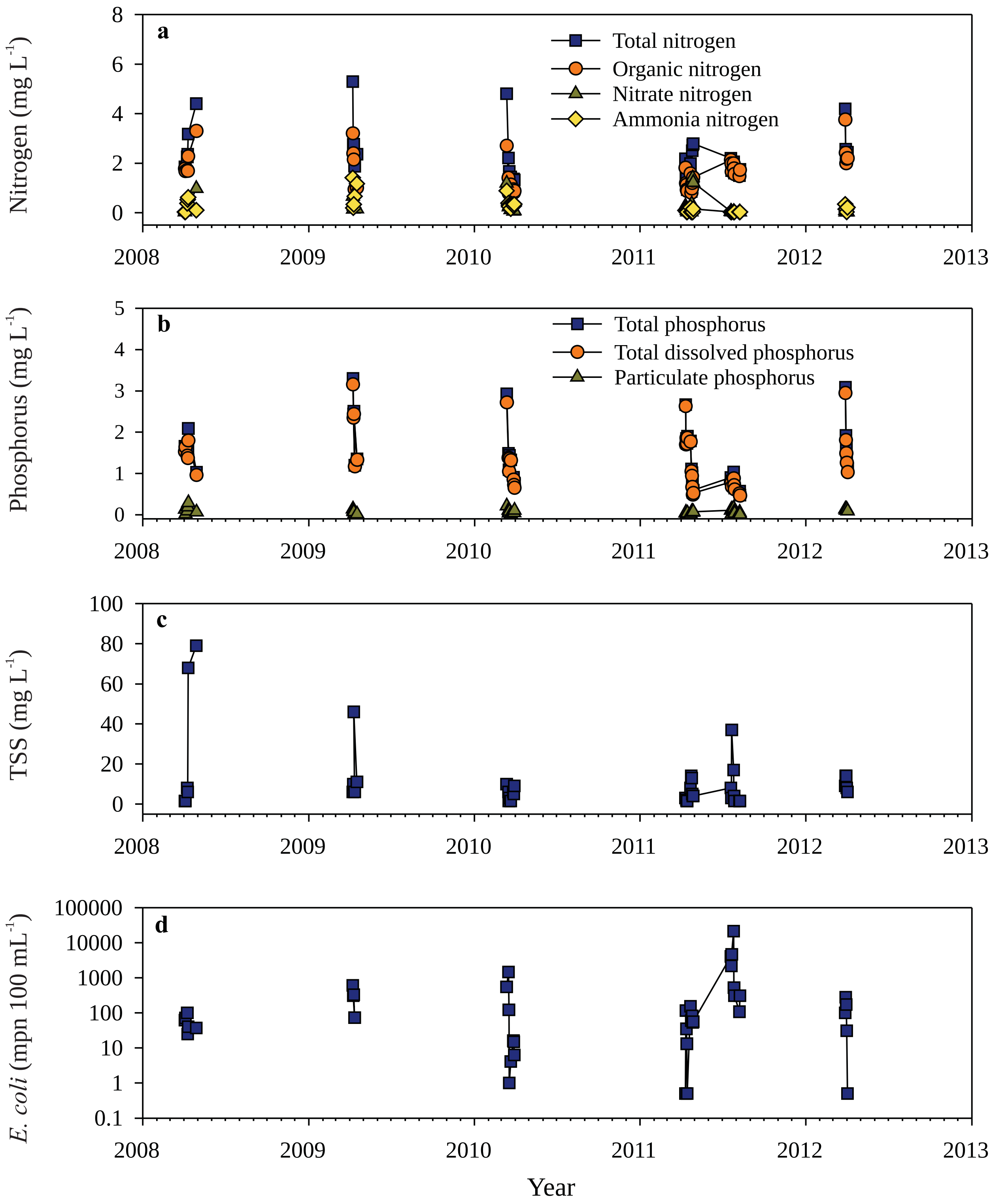

Figure 4.78. Concentrations of (a) nitrogen parameters, (b) phosphorus parameters, (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) measured at the edge-of-field Station 324 at the South Pasture from 2008 to 2012.

Table 4.83. Water quality parameter loads for Stations 324 at the South Pasture site from 2008 to 2012. [z]

Year	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
	($kg\ yr^{-1}$)							
2008	na[y]	na	na	na	na	na	na	na
2009	2.08	1.48	0.20	0.38	1.65	1.59	0.05	17.9
2010	1.00	0.62	0.16	0.20	0.69	0.64	0.05	2.85
2011	16.7	14.4	2.18	0.31	8.60	7.96	0.64	79.3
2012	7.57	7.10	0.09	0.42	4.97	4.60	0.38	34.4

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids.
[y] na = not available. Loads could not be determined because continuous flow data were not collected in 2008.

The water quality results suggest the rotational grazing BMP essentially had no positive effect on runoff water quality during snowmelt, and therefore the hypothesis was rejected. During the snowmelt periods, cattle were not present in the pasture. However, snowmelt runoff reflected the residual influence of cattle from the previous grazing season in term of fecal pats, urine deposits, and general condition of the pasture. As discussed previously, even though rotational grazing was adopted as a BMP, overstocking of the pasture continued, and in fact increased in the BMP period. Therefore, rotational grazing may be ineffective for the improvement of runoff water quality (and pasture health) until overstocking is addressed.

Unfortunately, because of a lack of rainfall runoff at this site in most years, a water quality assessment could not be done when cattle were actually present in the pasture. In 2011, when rainfall runoff did occur, cattle were not present in the south paddock, which had the drainage channel leading to Station 324 (Figure 4.71). Cattle were in the south paddock for 16 d from late June to mid-July (Table 4.76), which was prior to the rainfall runoff events in 2011. The fact that the cattle were not present in this paddock during active runoff can be considered an enhancement of the rotational grazing BMP by preventing direct cattle access to runoff water. As a consideration, avoiding pastures or paddocks with active runoff could also be used in deciding when and where to move cattle among pastures. Though, this may have some practical limitations. Another consideration for this site is that if we assume the presence of cattle during rainfall runoff represent a higher risk to water quality than during snowmelt or rainfall runoff without cattle, then perhaps the accumulative effects of rainfall runoff are not that critical as runoff events with the presence of cattle appear to be relatively rare at this site. The rainfall events that did generate runoff 2011 were atypical for July, with the amount of precipitation was more than double the 30-yr average for that month (Table 4.2).

Table 4.84. Average water quality parameter concentrations during the pre-BMP and post-BMP periods for snowmelt runoff at the South Pasture.[z]

Period	n	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl[y]	*E. coli* (mpn 100 mL^{-1})	EC (µS cm^{-1})	pH
		(mg L^{-1})											
Pre-BMP	19	2.43	1.68	0.29	0.44*a*	1.63	1.54	0.09	15	3.65*b*	213[x]	114*b*	7.49
Post-BMP	16	2.05	1.61	0.34	0.10*b*	1.55	1.48	0.07	7	5.92*a*	76	172*a*	7.55

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Chloride was added in late July 2008 (pre-BMP n =13).
[x] n = 18 instead of 19 because of a missing value for the April 17 sample.

4.11.4 Conclusions

- The rotational grazing BMP plan was successfully implemented in June 2010 when cattle were introduced into the pasture to begin the grazing season. Rotational grazing continued as scheduled in 2011 and 2012. The cost of the BMP was $3340 and most of this cost was for the initial implementation.
- The producer was pleased with the BMP, including the watering system, and the electric fences required minimal maintenance.
- Production cage data showed that the BMP had no positive effect on pasture health, supporting visual observations. Litter yield remained at a healthy with problems or unhealthy rating, and was likely caused by the continued overstocking practice. It was estimated that the number of animals should be reduced from 31 cow-calf pairs to about 5 to 9 pairs in order to avoid exceeding the carrying capacity of the pasture under current conditions.
- Extractable NO_3-N concentration was very low in the soil; whereas, STP concentration was moderately low or adequate in terms of soil fertility for optimum forage growth. The application of N fertilizer and a small amount of P fertilizer may be beneficial for pasture health recovery.
- In four out of five years, runoff was generated only by snowmelt at this site. Rainfall runoff occurred in only one year (2011) and represented 63% of the annual edge-of-field flow in that year. Because no pre-BMP rainfall runoff samples were collected, the comparisons between pre- and post-BMP periods were only possible using snowmelt samples.
- Total N consisted of 73% ON in snowmelt runoff and 98% in rainfall runoff. More than 90% of TP was in the form of TDP in snowmelt and rainfall.
- Generally, average concentrations in snowmelt did not vary greatly from year to year, and there was no consistent year effect on parameters. For many parameters, the highest concentrations were in 2009 and the lowest concentrations were in 2010 or 2011.
- The highest annual load values for nutrients and TSS in edge-of-field runoff was in the year with the highest annual flow.

- The concentration of NH_3-N was significantly reduced from the pre- to post-BMP period. In contrast, the concentrations of EC and Cl were significantly increased after BMP implementation. The average concentrations of all other parameters were not significant different between the pre- and post-BMP periods. Therefore, the rotational grazing BMP essentially had no positive effect on runoff water quality during snowmelt runoff, and the hypothesis was rejected.
- Improvement in pasture health or runoff water quality will likely not occur until the overstocking issue is addressed.

4.12 Reference 1 Site

4.12.1 Introduction

The REF1 site was one of two reference sites in the WHC Sub-watershed selected using similar criteria as for the BMP sites. The purpose of reference sites was to monitor annually cropped fields that had not recently received applications of manure. The REF1 site had not received manure in the recent past (5 yr or more), and it was anticipated that this site would not have manure applied for the duration of study. Unfortunately, because of the high cost of commercial fertilizer, the producer applied manure in fall 2008. Development of a nutrient management BMP was considered, but because of the subsequent reduction in fertilizer prices, the producer returned to using commercial fertilizer for the remainder of the project. Therefore, water quality monitoring was continued for the original purpose. Water quality at this site was monitored using two stations: one upstream to monitor run-on and one station downstream at the edge of field to monitor runoff.

4.12.2 Methods

4.12.2.1 Site Description and Management

The REF1 site was located in the south-central part of the sub-watershed and was adjacent to the south side of the SFD site (Figure 4.3). The site was a single cropped field and it occupied the north part (34 ha) of a quarter section (Figure 4.79). Trees and shrubs were along most of the perimeter of the field. The field contained a shallow drainage channel, which entered the field along the west side and exited on the east side.

The REF1 site was in the same AGRASID soil landscape model (CYLP2/U1hc) as described for a portion of the NFD (Alberta Soil Information Centre 2013) (Sub-section 4.7.2.1). The surface soil at the site had a loam texture (36% sand, 19% clay), a pH of 5.6, electrical conductivity of 0.6 dS m^{-1}, 2950 mg kg^{-1} TN, 696 mg kg^{-1} TP, and 6.9% organic matter (Appendix 4).

From 2007 to 2012, the crop rotation used at this site was potato, corn silage, canola, wheat, and potato (Table 4.85). In the spring, the field was typically tilled prior to fertilizing and seeding, except in 2009 and 2010. Inorganic fertilizer was surface applied prior to seeding potatoes, or banded with the seed when other crops were grown. Additional granular fertilizer was applied to the potato crop after seeding in 2007, and additional liquid fertilizer was banded with the potato crop in 2011. Rollers were used following the seeding of wheat in 2010.

Herbicides were applied one to three times from the beginning of May to early July in all years (Table 4.86). Fungicide was applied in early July when canola was grown. Potato and wheat crops were desiccated with an herbicide in late August to early September, 2 to 4 wk prior to harvest. Canola was swathed, and corn silage directly harvested. In 2011, only 28 ha out of 32 ha were harvested due to waterlogged field conditions. The field was tilled in 2007 and 2010 after harvest

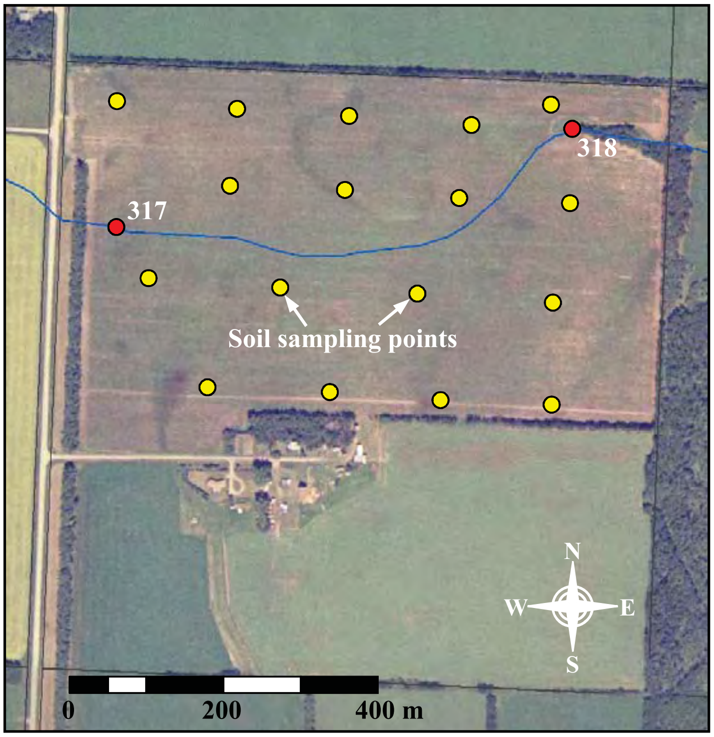

Figure 4.79. Reference 1 site showing the upstream (317) and downstream (318) water monitoring stations and the agronomic soil sampling points.

Table 4.85. Crop seeding and fertilizer details for the Reference 1 site from 2007 to 2012.[z]

Year	Crop	Seeding date	Tillage date	Tillage depth (cm)	Fertilizer N	Fertilizer P	Fertilizer K	Fertilizer S	Potato hilling date
					------------ (kg ha^{-1}) ------------				
2007	Potato	May 7	May 7	15	na[y,x]	na	na	na	June 1
					22[w]	0	0	27	
2008	Corn	May 6	May 6	10	60[v]	9	19	11	
2009	Canola	May 14	-	-	12[u]	0	0	13	
2010	Wheat	May 3	-	-	101	11	39	17	
2011	Potato	May 16-17	May 16	10-12.5	101[t]	0	179	25	June 11
					15[s]	15	0	0	
2012	Wheat	May 15	May 14	7.5	78	17	22	11	

[z] Some dates were estimated.
[y] na = not available.
[x] Unknown rate of 75-50-130 fertilizer broadcasted on May 5.
[w] 112 kg ha^{-1} of 20-0-0-24 fertilizer broadcasted on May 31.
[v] 224 kg ha^{-1} of 27-7-10-5 fertilizer broadcasted on May 6. 77.5 Mg ha^{-1} of liquid hog manure was applied on October 21.
[u] 56 kg ha^{-1} of 21-0-0-24 fertilizer broadcast on May 14.
[t] Fertilizer broadcasted on May 16.
[s] Liquid fertilizer applied with potatoes on May 16 and 17.

Table 4.86. Pesticide and harvest details for Reference 1 site from 2007 to 2012.[z]

Year	Type[y]	Pesticide Product	Pesticide Date	Pre-harvest Method[x]	Pre-harvest Date	Harvest	Yield (Mg ha^{-1})	Cultivation
2007	H	Sencor®, Venture® L	Jun 17	-	-	Sep 5	29.1	Oct 10
	H	Venture® L	Aug 20					
	H	Reglone®	Aug 30					
2008	H	Roundup®	Jun 6	-	-	Oct 15	33.6	Oct 22
	H	Roundup®	Jun 30					
2009	H	Liberty®	Jun 5	S	Sep 14	Oct 1	3.3	-
2010	H	Roundup®	May 5	D	Sep 6	Oct 10	5.6	Oct 20 (2x)
	H	Express® SG	May 24					
	H	Frontline®, Axial®	Jun 12					
	F	Tilt®	Jun 29					
2011	H	Gramoxone®	Jun 9	-	-	Sep 12-13	35	-
	H	Prism®, Sencor®, Eptam®	Jul 5					
	H	Reglone	Sep 1					
	H	Reglone	Sep 8					
2012	H	Everest®, Frontline®	Jun 12	D	Aug 24	Sep 18	5.5	-
	F	Fungicide	Jul 5					

[z] Some dates were estimated.
[y] H = herbicide, F = Fungicide.
[x] S = swath, D = desiccant.

and in 2008 after manure application. Liquid hog manure was surface applied at a rate of 77.5 Mg ha^{-1} on October 21, 2008. Because of the applied manure, only a small amount of N and S fertilizer was applied with the canola seed in spring 2009.

4.12.2.2 Soil and Manure Samples

Soil characterization samples (Sub-section 2.9) were collected on October 22, 2009, agronomic 0- to 15-cm samples were collected annually (2007 to 2012), and pre- and post-seeding samples were collected in spring 2011.

Agronomic samples were collected using a grid pattern from a total of 17 sampling points (Figure 4.79). The pre- and post-seeding samples were collected to determine the difference in soil nutrient concentrations following the application of commercial fertilizer. The samples were collected with a Dutch auger from 0 to 15 cm using the agronomic 200-m grid. Data from the spring agronomic samples were used to represent the post-seeding nutrient concentrations (Sub-section 2.9).

A few days prior to manure application in fall 2008, two composite samples of liquid hog manure was collected and then analyzed (Sub-section 2.10).

4.12.2.3 Water Flow and Quality

The REF1 site was equipped with two water monitoring stations in the field drainage channel: one upstream (Station 317), which was within the field near the west side of the quarter section, and the other downstream (Station 318) near the east side of the quarter section (Figure 4.79). Both stations were equipped with circular flumes and automatic Isco water samplers (Sub-sections 2.6, 2.7, and 2.8).

Descriptive statistics 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 statistics for days when there was connective flow between the upstream and downstream stations. Total annual loads were calculated as described in Sub-section 2.8.4.

4.12.3 Results and Discussion

4.12.3.1 Manure and Soil

Manure. The liquid hog manure applied to the site in October 2008 consisted of 97.4% water. The average nutrient content was 2.6 kg Mg^{-1} NH_4-N, 3.7 kg Mg^{-1} TN, and 0.6 kg Mg^{-1} TP on a wet-weight basis.

Agronomic soil samples. On average, extractable NO_3-N concentration was about 2.5-fold higher in the spring compared to the fall (Table 4.87). The higher concentrations in the spring were likely the result of added N fertilizer (Table 4.85) followed by a decrease during the crop season. The high value in spring 2009 was likely caused by the manure applied in the previous fall.

Extractable NH_4-N concentration fluctuated, but was generally higher in the spring (Table 4.87). One noted exception was the relatively high NH_4-N concentration in fall 2008. Soil samples were taken 7 d after liquid hog manure was applied in October 2008. Assuming the concentration would have been about 5 to 6 mg kg^{-1}, the 30 mg kg^{-1} in the top 15-cm of soil could easily be accounted for based on the NH_4-N content and application rate of the manure. After application and incorporation, NH_4-N in manure typically converts quickly to NO_3-N. However, because the soil sampling was done soon after manure application, there may not have been enough time for the nitrification process to have fully occurred. Also, in October, the average daily temperature (-3.2 to +6.6 ^{o}C) was cooler and less than zero at nights and this would have slowed nitrification.

The concentration of STP fluctuated but with no apparent trend (Table 4.87). Concentration values were less than the agronomic threshold of 60 mg kg^{-1} (Howard 2006), which is typical for a cropped field that receives no or very little manure. Unlike NH_4-N, manure application did not cause an obvious change to STP in fall 2008. However, the highest concentration of STP was in spring 2009, and may have been the result of the manure applied in the previous fall.

Pre- and post-seeding soil samples. Extractable NO_3-N concentration was significantly increased by five-fold from pre- to post-seeding (Table 4.88). This increase was likely the result of the 116 kg ha^{-1} of N fertilizer that was added (Table 4.85) 12 d after the pre-seeding samples and 16 d before the post-seeding samples were taken. Depending on the placement of the fertilizer and soil-water interaction zone, the potential risk of N loss may have increased. The average concentration of NH_4-N was higher in the post-seeding samples, but was not significantly different from the pre-seeding samples. The concentration of STP was also not significantly different between the two sampling times and was actually slightly less in the post-seeding samples. The amount of added P fertilizer was quite low in 2011, with the application of 15 kg ha^{-1} of P.

4.12.3.2 Water Flow and Quality

Water flow. In two out of five years, flow did not occur at the downstream Station 318 (Table 4.89). Lower than average precipitation during the preceding fall and winter seasons (Sub-section 4.2.2) resulted in no flow in 2009 and 2010 at Station 318. In these years, flow at the upstream Station 317 was too small (Figure 4.80) to generate connective flow along the channel and reach Station 318. The largest annual flows occurred in 2011 followed by 2012. Connective flow did occur between the two station in 2011 and 2012. The flow at Station 318 in 2008 was entirely from

Table 4.87. Average concentrations of nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) in the agronomic soil samples (0 to 15 cm) collected from 2007 to 2012 at the Reference 1 site.

	NO_3-N		NH_4-N		STP	
	Spring	Fall	Spring	Fall	Spring	Fall
Year	(mg kg^{-1})					
2007	ns[z]	11	ns	5	ns	40
2008	33	10	6	35	28	40
2009	42	13	25	5	46	38
2010	24	8	15	5	39	34
2011	21	13	18	6	22	34
2012	17	ns	8	ns	31	ns

[z] ns = not sampled.

Table 4.88. Average nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) values for pre- and post-seeding soil samples collected at the Reference 1 site in 2011.

	NO_3-N	NH_4-N	STP
	(mg kg^{-1})		
Pre-seeding[z]	4a[y]	4a	29a
Post-seeding[x]	21b	18a	22a

[z] Pre-seeding samples collected May 4, 2011.
[y] Averages for each parameter followed by the same letter are not significantly different (P <0.1).
[x] Post-seeding samples collected June 1, 2011.

within the field; whereas, flow in 2011 and 2012 was a combination of run-on (flow through Station 317) and runoff from the field. The small amount of flow in 2008 occurred entirely during snowmelt runoff. At Station 317, flow was dominated by rainfall in 2010. At Station 318, snowmelt dominated flow in 2012. Snowmelt and rainfall roughly contributed equally to flow in 2011 at Station 318 and in 2012 at Station 317. It is interesting that in 2011 and 2012, the proportion of flow caused by rainfall was less at Station 318 compared to Station 317, and vice versa for snowmelt. Perhaps the connectivity between the two stations and runoff derived from the field were less during rainfall because of surface conditions and the presences of a crop.

Water quality. Average (all years) concentrations of TN, NO_3-N, and NH_3-N were several fold (2 to 19) higher in snowmelt runoff than in rainfall runoff; whereas, ON concentration was similar between the two runoff types (Table 4.90). The average concentration of TP was only slightly higher in snowmelt at Station 317 and the same in snowmelt and rainfall runoff at Station 318. The majority (69 and 74%) of TN was in the form of NO_3-N plus NH_3-N in snowmelt for Station 317 and 318, respectively. However, in rainfall runoff, the majority (67 and 81%, respectively) of TN was in the form of ON. The majority of TP was in the form of TDP ranging, on average, from 64 to 92% among the two stations and two runoff types. At both stations, the concentrations of most parameters during snowmelt were highest in 2012; whereas, the concentration of most parameters during rainfall runoff was highest in 2011. The average concentration of TSS was five-fold higher in snowmelt runoff and two-fold higher in rainfall runoff at Station 318 compared to Station 317. Similarly, concentration of PP was three-fold higher in snowmelt runoff and two-fold higher in rainfall runoff at Station 318. This suggests that the cropped field, through which the shallow channel bisected, was a source of particulate material.

Since no flow occurred at the downstream Station 318 in 2009 and 2010 (Table 4.89), yearly water quality comparisons were made with Station 317 in 2008, 2011, and 2012 on days when there was connective flow and both stations were sampled using the same sampling method. The TP and TDP concentrations were greater at the upstream station than the downstream station, except for TP during snowmelt in 2012 (Table 4.91). This may suggest that runoff from the field had lower dissolved P concentration than in the run-on entering the field. This is likely since the STP concentration in this field was low and less than the agronomic threshold of 60 mg kg^{-1}. In contrast, the average concentration of PP and TSS were nearly always higher at the downstream station, except for TSS during snowmelt in 2008. The more erodible surface of the cultivated field was likely a source for soil loss leading to higher TSS and PP concentrations at the edge-of-field.

Table 4.89. Annual flow and proportions attributed to snowmelt and rainfall runoff for Stations 317 (upstream) and 318 (downstream) at Reference 1 site from 2008 to 2012.

	Station 317			Station 318		
Year	Annual flow (m^3 yr^{-1})	Proportion as snowmelt (%)	Proportion as rainfall (%)	Annual flow (m^3 yr^{-1})	Proportion as snowmelt (%)	Proportion as rainfall (%)
2008	4,592	100	0	1,128	100	0
2009	764	100	0	0	0	0
2010	62	0	100	0	0	0
2011	84,068	38	62	101,259	53	47
2012	15,382	52	48	13,085	86	14

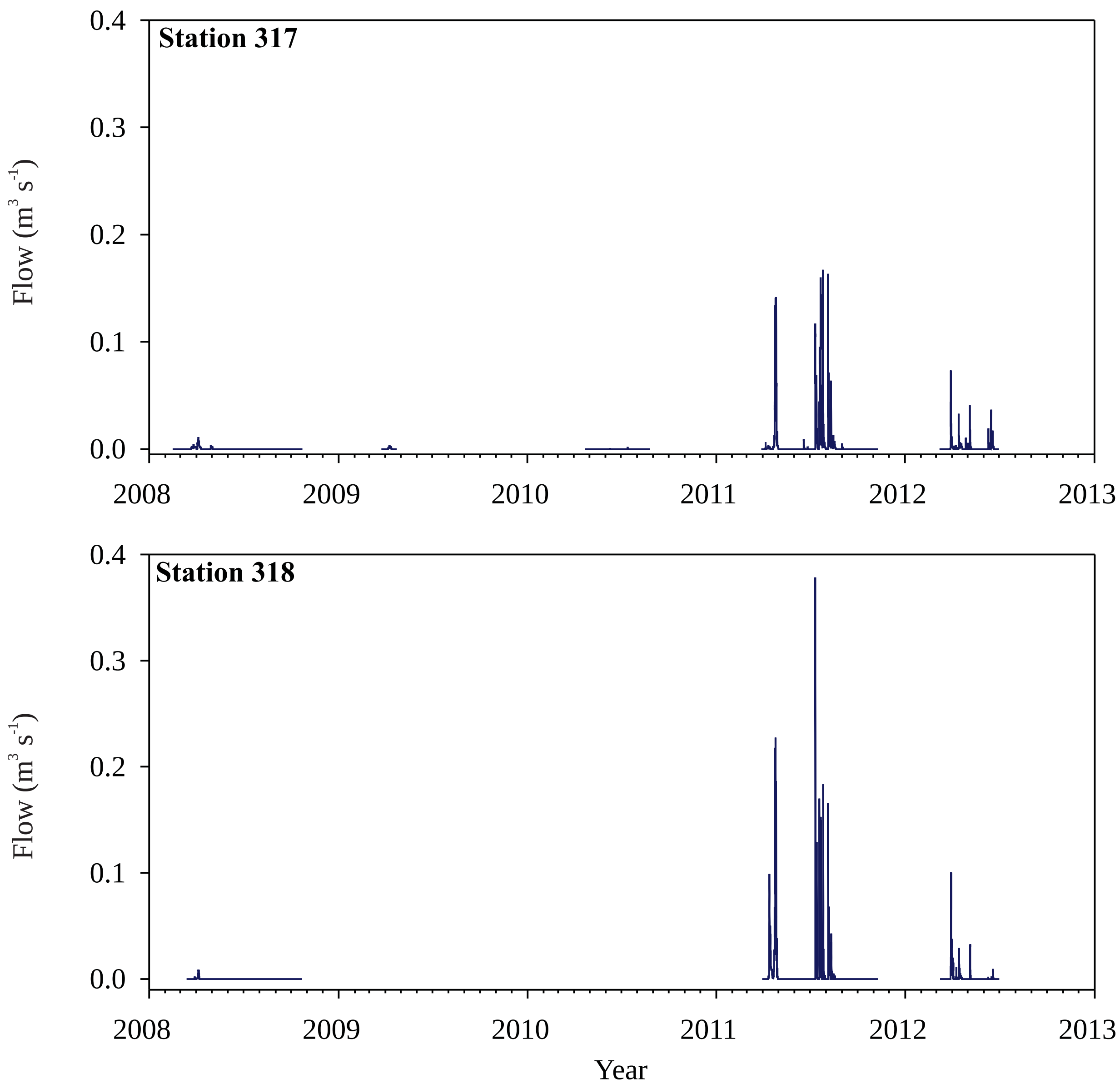

Figure 4.80. Hydrographs for Stations 317 to 318 at the Reference 1 site from 2008 to 2012.

Nitrogen was less consistent. In two of the three years for snowmelt runoff, the concentrations of most N parameters were higher at Station 317 (Table 4.91). In contrast, most of the N parameters had higher average concentrations in rainfall runoff at Station 318. Perhaps during snowmelt there was a dilution effect caused by runoff from the field; whereas, during rainfall, runoff from the field had an opposite effect. The average concentrations of Cl, *E. coli*, and EC were consistently higher at the upstream Station 317 compared to the downstream Station 318, further suggesting a dilution effect from runoff originating from the field.

Table 4.90. Average water quality parameters at Stations 317 (upstream) and 318 (downstream) at the Reference 1 site from 2008 to 2012.[z]

Year[y]	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli* (mpn 100 mL^{-1})	EC ($\mu S\ cm^{-1}$)	pH
	----------	----------	----------	----------	($mg\ L^{-1}$)	----------	----------	----------	----------			
					Station 317 - snowmelt							
2008 (18)	3.48	2.67	0.49	0.28	1.02	0.89	0.13	71	na[x]	22	296	7.74
2009 (4)	9.70	3.25	1.08	5.28	3.28	3.16	0.12	8	11.7	16	255	7.89
2011 (18)	8.30	2.34	5.50	0.41	1.09	1.03	0.05	11	19.7	10	305	7.72
2012 (12)	22.8	4.74	17.5	0.52	0.92	0.78	0.15	41	65.6	14	671	7.83
All (52)	10.1	3.08	6.20	0.77	1.19	1.09	0.11	39	34.9	15	382	7.77
					Station 318 - snowmelt							
2008 (8)	7.05	3.46	2.58	0.79	0.94	0.72	0.22	30	na	23	282	7.30
2011 (16)	11.0	2.69	8.08	0.18	0.95	0.83	0.12	37	22.8	6	226	6.74
2012 (12)	18.6	3.59	14.0	0.84	1.15	0.36	0.79	496	39.4	8	404	7.51
All (36)	12.7	3.16	8.85	0.54	1.01	0.65	0.36	189	29.9	11	298	7.12
					Station 317- rainfall							
2010 (1)	1.48	1.39	0.04	0.03	1.03	0.94	0.09	11	0.56	225	223	7.84
2011 (14)	4.92	3.02	1.84	0.04	1.29	1.12	0.17	69	17.0	1131	417	7.97
2012 (7)	4.19	3.24	0.91	0.04	0.47	0.41	0.05	11	61.7	120	786	8.13
All (22)	4.53	3.02	1.46	0.04	1.02	0.89	0.13	48	30.5	768	525	8.02
					Station 318 - rainfall							
2011 (10)	3.98	3.25	0.65	0.07	1.32	0.92	0.40	157	11.5	373	281	7.60
2012 (5)	4.09	3.21	0.82	0.06	0.39	0.28	0.11	36	50.8	135	544	8.03
All (15)	4.02	3.23	0.70	0.07	1.01	0.71	0.30	117	24.6	294	369	7.74

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Number of samples are shown in parenthesis. Averages are for all data including data collected on days when flow was not connective and the sampling methods (grab and ISCO) were different between Stations 317 and 318.
[x] na = not available. Chloride was added in late July 2008.

Unlike the soil results, the application of liquid hog manure in fall 2008 did not have an obvious effect on runoff water quality. As it turned out, there was no edge-of-field runoff in 2009 and 2010. Runoff in 2011 was about 2.5 yr after the manure was applied, and there was likely little residual effect. The application of manure in 2008 was the only time manure was applied during the study. The soil at this site was not excessive in N and P and was not considered a high-risk agricultural field for nutrient loss in runoff. Several years of manure application would be required, particularly if applied in excess of crop nutrient requirements, to increase the risk of nutrient loss from manure.

The annual nutrient and TSS loads were 1.4- to 16.5-fold greater in 2011 compared to 2012, depending on the parameter (Table 4.92). The higher loads in 2011 was the result of the higher annual flow in that year compared to 2012 (Table 4.89).

Table 4.91. Average concentration of water quality parameters at Stations 317 (upstream) and 318 (downstream) at the Reference 1 site from 2008 to 2012 when flow was connective and sampled on the same day using the same sampling method.[z]

Station	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli* (mpn 100 mL^{-1})	EC (μS cm^{-1})	pH
	(mg L^{-1})											
					2008 - snowmelt (7) [y]							
Upstream	4.11	2.92	0.82	0.31	1.31	1.12	0.18	110	na[x]	31	297	7.54
Downstream	7.02	3.40	2.65	0.75	0.93	0.71	0.22	31	na	25	290	7.33
					2011 - snowmelt (3)							
Upstream	12.8	3.13	8.68	0.96	1.60	1.53	0.07	16	29.1	6	366	7.71
Downstream	8.85	3.01	5.60	0.22	1.18	0.82	0.36	157	20.0	3	200	6.95
					2012 - snowmelt (12)							
Upstream	22.8	4.74	17.5	0.52	0.92	0.78	0.15	41	65.6	14	671	7.83
Downstream	18.6	3.59	14.0	0.84	1.15	0.36	0.79	496	39.4	8	404	7.51
					2011 - rainfall (7)							
Upstream	3.15	3.02	0.08	0.05	1.75	1.52	0.23	109	13.3	1780	438	8.01
Downstream	3.62	3.27	0.27	0.07	1.49	1.00	0.49	205	11.6	370	318	7.75
					2012 - rainfall (5)							
Upstream	3.54	3.32	0.18	0.04	0.48	0.43	0.05	11	55.7	142	797	8.17
Downstream	4.09	3.21	0.82	0.06	0.39	0.28	0.11	36	50.8	135	544	8.03

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] Number of samples are shown in parenthesis. Averages are for data collected on days when flow was connective and the sampling methods (grab or ISCO) were the same at Stations 317 and 318.
[x] na = not available. Chloride was added in late July 2008.

Table 4.92. Annual nutrient and TSS loads at the downstream Station 318 at the Reference 1 site from 2008 to 2012.[z]

Year	TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
	(kg yr^{-1})							
2008	7.47	3.77	2.70	0.81	1.18	0.93	0.25	34.6
2009	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0
2011	751	311	414	24.1	136	95.3	40.3	16,215
2012	220	45.5	160	11.7	22.3	5.76	16.5	11,338

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids.

4.12.4 Conclusions

- Soil extractable N and P concentrations were not excessive at this site, and this was expected for a cropped field that had received no or very little manure. Therefore, this field was not considered a high risk for nutrient loss in terms of soil nutrient status.
- The single manure application in 2008 seemed to have caused a short-term elevation of extractable nutrients in the surface soil.
- The application of commercial fertilizer in spring 2011 significantly increased extractable NO_3-N five-fold in the top 15-cm of soil. Depending on the placement of the fertilizer and soil-water interaction zone, the potential risk of N loss may have increased. The concentration of NH_4-N and STP were not significantly different between pre- and post-seeding samples.
- Edge-of-field runoff from this site was a combination of run-on water and runoff water generated from within the field. In some years, edge-of-field runoff originated only from within the field; whereas, in other years, connective flow occurred along the length of the drainage channel and runoff included run-on water. Still, in other years, no runoff occurred. Edge-of-field annual flow ranged from 0 to 101,259 m^3 yr^{-1}, and runoff hydrology was governed by the amount of precipitation.
- In years that flow occurred, 53 to 100% of annual edge-of-field runoff was attributed to snowmelt.
- Average concentrations of TN, NO_3-N, and NH_3-N were 2- to 19-fold higher in snowmelt runoff than in rainfall runoff. Average concentration of TP was either only slightly higher in snowmelt runoff or the same in snowmelt and rainfall runoff.
- The majority of TN was in the form of NO_3-N plus NH_3-N in snowmelt; whereas, ON was the dominate form in rainfall runoff. The majority of TP was consistently in the form of TDP.
- During the years (2011 and 2012) when connective flow occurred between the two stations, the risk of loss of dissolved and particulate P appeared to differ. The concentrations of TDP decreased from upstream to downstream; whereas, PP increased. This suggests that runoff within the field caused a dilution effect for TDP and contributed to PP loss. The latter was also true for TSS and this may reflect the higher erosion potential of the field.
- For N, runoff had a dilution effect caused by snowmelt from the field; whereas, during rainfall, runoff from the field had the opposite effect.
- The average concentrations of Cl, *E. coli*, and EC were consistently higher at the upstream station compared to the downstream station, further suggesting a dilution effect from runoff originating from the field.
- The annual nutrient and TSS loads at the edge-of-field were 1.4- to 16.5-fold greater in 2011 compared to 2012. The higher loads in 2011 were caused by higher annual flow, which was nearly eight-fold greater than in 2012.

4.13 Reference 2 Site

4.13.1 Introduction

The REF2 site was selected with the same purpose as REF1, to monitor an annually cropped field that had no manure application (Sub-section 4.12). As for REF1, the REF2 producer applied manure in the fall of 2008 because of the increased cost of commercial fertilizer, but then returned to using commercial fertilizers for the remainder of the study. Water quality at this site was monitored using a single edge-of-field station.

4.13.2 Methods

4.13.2.1 Site Description and Management

The REF2 site was located in the northeast portion of the sub-watershed and relatively near the outlet (Figure 4.3). The site was an annual cropped field approximately 52 ha in size. The crop rotation consisted of canola and cereals. There was a farmyard in the southern part of the quarter section (Figure 4.81). A low wet area extended from the north side of the farmyard to the northeast corner of the quarter section, and a groundwater spring was identified as a source of water.

The REF2 site was in the same AGRASID soil landscape model (PED10/U1h) as described for the NPS (Alberta Soil Information Centre 2013) (Sub-section 4.10.2.1). The surface soil at the site

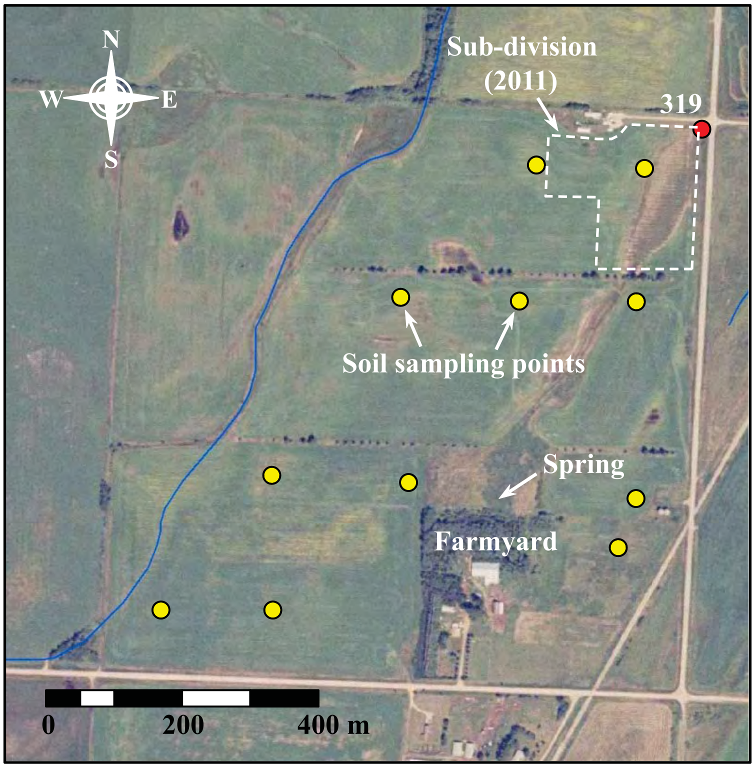

Figure 4.81. The Reference 2 site showing the location of the water monitoring Station 319, the soil sampling points, and the groundwater spring discharge.

had a silty loam texture (28% sand, 21% clay), a pH of 6.5, electrical conductivity of 0.6 dS m^{-1}, 5040 mg kg^{-1} TN, 886 mg kg^{-1} TP, and 11.2% organic matter (Appendix 4).

Prior to 2007, the REF2 site had been rented by the current producer for the previous 3 to 4 yr and was used to grow annual crops and no manure was applied. A portion of the field (16 ha) could not be seeded in spring 2007 because the soil was too wet. Drier areas were seeded to canola (14 ha) and winter wheat (22 ha) (Table 4.93). The rest of the field was seeded to barley in spring 2008. The site was seeded to a single crop in other years, except in 2010 when it was chemical fallowed. Harrows were typically used prior to direct seeding. Commercial fertilizer was side-banded at the time of seeding. Additional fertilizer was also applied in some years, such as anhydrous ammonia in 2007 and surface broadcasting of fertilizer after seeding in 2007 and 2011. Liquid dairy manure was applied in fall 2008 at a rate of 45 Mg ha^{-1} and incorporated by disc tillage. Herbicides were applied near the time of seeding and in June (Table 4.94). Harvest was typically straight-cut, except in 2011 when canola was swathed 4 wk before combining.

In spring 2011, a 4-ha portion of the northeast corner of the REF2 site was sub-divided, and the new sub-division was cultivated, except for the drainage channel, but not seeded (Figure 4.81). On June 19, 2011, a truck was driven through the length of the channel to create ruts to facilitate drainage during the heavy rainfall at the time. In spring 2012, the sub-division was cultivated and seeded to grass. The exposed soil in spring 2011 and spring 2012 was a concern regarding increased sediment loss and runoff potential.

Table 4.93. Seeding and fertilizing details at the Reference 2 site from 2007 to 2012.[z]

Year	Area (ha)	Crop	Seeding date	Fertilizer N	P	K	S	Harrowing
				(kg ha^{-1})				
2007[y,x]	14	Canola	May 20	107	10	0	40	May 5
2008[w]	22	Winter wheat	Sep 5, 2007	49	10	0	0	
	30	Barley	May 8	na[v]	na	na	na	na
2009	52	Wheat	May 25	0	0	0	0	-
2010	-	Fallow	-	0	0	0	0	-
2011[y,u]	40	Canola	May 31	74	2	5	18	May 30
2012	48	Wheat	May 22	78	22	11	0	May 21

[z] Some dates were estimated.
[y] Part of field was too wet to seed in the spring.
[x] Application of NH_3 (82-0-0) at 55 kg ha^{-1} and 10-50-0 fertilizer at 45 kg ha^{-1}applied on May 15, 2007, and 168 kg ha^{-1} of 21-0-0-24 broadcasted on May 20, 2007.
[w] Application of NH_3 (82-0-0) at 82 kg ha^{-1} and 10-50-0 fertilizer at 45 kg ha^{-1} applied on September 5, 2007. Liquid dairy manure was applied at a rate of 45 Mg ha^{-1} in fall 2008.
[v] na = not available
[u] 112 kg ha^{-1} of 35-5-5-10 side-banded with seed on May 31, 2011, and 168 kg ha^{-1} of 21-0-0-4 broadcasted on about June 2, 2011.

Table 4.94. Pesticide and harvest details at the Reference 2 site from 2007 to 2012.[z]

Year	Area (ha)	Pesticide Product	Pesticide Date	Harvest	Yield (Mg ha^{-1})	Cultivation
2007	22	Roundup®	Jul 15	-	-	-
		Herbicide®	Sep 30			
	14	Roundup®	Jun 1	Sep 27	na[y]	
	16	Roundup®	Jul 15	-	-	Sep 5[x]
2008	52	na	na	na	na	na[w]
2009	52	Roundup® Transorb	May 30	Nov 10-13[v]	4.03	-
		Altitude® FX	Jun 19			
2010	52	Roundup®	Jun 7	-	-	-
		Roundup®, Express®	Aug 21			
2011	48	CleanStart®	May 27	Oct 18	1.23	-
2012	48	Roundupr®	May 12	Oct 16	4.91	-
		Everest 2.0®, Spectrum®	Jun 20			
		Tilt®, Nexus®	Jun 20			

[z] Some dates were estimaed.
[y] na = not available.
[x] Disc applied to 8 ha of north half.
[w] Manure application was incorporated with disc tillage at unknown date.
[v] Harvested for feed grain with variable yield due to hail and frost damage. An area of about 16 ha yielded 336 kg ha^{-1}.

4.13.2.2 Soil Sampling

Soil characterization samples (Sub-section 2.9) were collected on December 1, 2009, Agronomic 0- to 15-cm samples were collected annually from 2007 to 2012, and pre- and post-seeding samples were collected in spring 2011.

The agronomic samples were collected in a grid pattern from a total of 11 sampling points from fall 2007 to spring 2012. As a result of the 4-ha sub-division, soil samples were taken from three sampling points within the sub-division and 10 sampling points were used in the remaining area of the REF2 site in fall 2011 and spring 2012.

Pre- and post-seeding samples were collected in 2011 to determine the difference in soil nutrient concentrations following the application of commercial fertilizers. The samples were collected with a Dutch auger from 0- to 15-cm using the agronomic 200-m grid. Data from the agronomic samples were used to represent the post-seeding nutrient concentrations (Sub-section 2.9).

4.13.2.3 Water Flow and Quality

The REF2 site was equipped with an edge-of-field water monitoring station (Station 319) in the northeast corner of the quarter section (Figure 4.81). The monitoring station consisted of a circular flume and an automatic Isco water sampler (Sub-sections 2.6, 2.7, and 2.8).

Descriptive statistics 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 statistics. Total annual loads were calculated as described in Sub-section 2.8.4.

4.13.3 Results and Discussion

4.13.3.1 Soil

Agronomic samples. On average, extractable NO_3-N concentration was nearly two-fold higher in the spring compared to the fall (Table 4.95). The higher concentrations in the spring were likely the result of added N fertilizer (Table 4.93) followed by a decrease during the crop season. The crop was fallowed in 2010 and no nutrients were applied that spring, and as a result, the lowest average extractable NO_3-N concentration was observed in spring 2010. Extractable NH_4-N concentration was less than 8 mg kg^{-1} in the fall, expect in 2008 when it was 14 mg ha^{-1}. This higher concentration was likely caused by the added manure in fall 2008. The cause of the even higher concentration of NH_4-N in spring 2012 is unknown. The concentration of STP was similar between spring and fall, and the overall average concentration was low (<18 mg kg^{-1}) (Table 4.95). Concentration values were well less than the agronomic threshold of 60 mg kg^{-1} (Howard 2006), which is typical for a cropped field that receives no or very little manure. The application of manure did not cause an obvious change to STP in fall 2008 or spring 2009. Overall, the nutrient status was low in this field and the application of N and P fertilizer is required for optimum crop growth. Also, this field was not considered a high risk for nutrient loss in terms of soil nutrient status.

The concentrations of NO_3-N, NH_4-N, and STP in the soil samples collected from the new sub-division in 2001 and 2012 were similar to the rest of the REF2 site (Table 4.96). Extractable NO_3-N concentration in fall 2011 was somewhat higher compared to the rest of field and to the fall averages of other years. This may have been caused by the lack of crop growth in the sub-division in 2011, and hence, no uptake of N.

Pre- and post-seeding samples. Extractable NO_3-N and NH_4-N increased slightly and STP concentration decreased slightly from pre- to post-seeding (Table 4.97). However, the average differences were not statically significant. The application of fertilizer in 2011 was split between side-banding of 39 kg ha^{-1} N and a small amount of P at the time of seeding and surface broadcasting of 35 kg ha^{-1} N and no P a few days after seeding. It is uncertain whether or not the surfacing broadcasting of fertilizer was done prior to or after the post-seeding soil samples were collected on June 2, 2011. The lack of response of STP can be explained by the small amount of P that was applied.

Table 4.95. Average (n = 11) concentrations of nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) in the agronomic soil samples (0 to 15 cm) collected from 2007 to 2012 at the Reference 2 site.

	NO_3-N		NH_4-N		STP	
	Spring	Fall	Spring	Fall	Spring	Fall
Year	(mg kg^{-1})					
2007	ns[z]	11	ns	7	ns	21
2008	29	8	8	14	16	16
2009	14	8	7	7	18	21
2010	6	9	6	6	18	16
2011[y]	12	7	11	4	17	14
2012[y]	19	ns	23	ns	17	ns

[z] ns = not sampled.
[y] Fall 2011and spring 2012 averages were based on 10 sampling points as a result of the sub-division.

Table 4.96. Average (n = 3) concentrations of nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) in the agronomic soil samples (0 to 15 cm) collected within the sub-division at Reference 2 site in fall 2011 and spring 2012..

	NO_3-N	NH_4-N	STP
Year	(mg kg^{-1})		
2011 (fall)	22	4	24
2012 (spring)	26	6	21

Table 4.97. Average nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and soil-test phosphorus (STP) values for pre- and post-seeding soil samples collected at the Reference 2 site in 2011.

	NO_3-N	NH_4-N	STP
	(mg kg^{-1})		
Pre-seeding[z,y]	8	6	21
Post-seeding[y,x]	12	11	17

[z] Pre-seeding samples collected May 4, 2011.
[y] Averages for each parameter were not significantly different (P <0.1).
[x] Post-seeding samples collected June 2, 2011.

4.13.3.2 Water Flow and Quality

Water flow. Flow occurred during snowmelt and rainfall periods in nearly all years during the study, except for 2009, which had no rainfall-generated runoff at this site (Table 4.98 and Figure 4.82). Annual flow ranged from 980 m^3 yr^{-1} in 2009 to 57,766 m^3 yr^{-1} in 2011, with an 5-yr average of nearly 23,500 m^3 yr^{-1} (Table 4.98). The two years with the highest annual flows (2010 and 2011) also had the highest total annual precipitation, which was greater than the 30-yr average for both years (Sub-section 4.2.2). The two years with the lowest annual flows (2008 and 2009) also had the lowest total annual precipitation, which was less than the 30-yr average for both years. In addition to direct surface runoff from snowmelt and rainfall, it was observed that during rainfall events in 2008, 2010, and 2011, groundwater discharge in the northeast corner of the site contributed to runoff.

The proportional distribution between snowmelt and rainfall runoff ranged from all of the flow in 2009 caused by snowmelt to nearly all of the flow in 2010 caused by rainfall (Table 4.98). In 2009, much of the monthly precipitation from April to September was less than 30-yr averages (Sub-section 4.2.2), resulting in no rainfall runoff (Figure 4.82). In 2010, there was less than

Table 4.98. Annual flow and proportions attributed to snowmelt and rainfall runoff at the Reference 2 site from 2008 to 2012.

Year	Annual flow (m^3 yr^{-1})	Proportion as snowmelt (%)	Proportion as rainfall (%)
2008	12,992	44	56
2009	980	100	0
2010	26,176	2	98
2011	57,766	51	49
2012	19,433	51	49

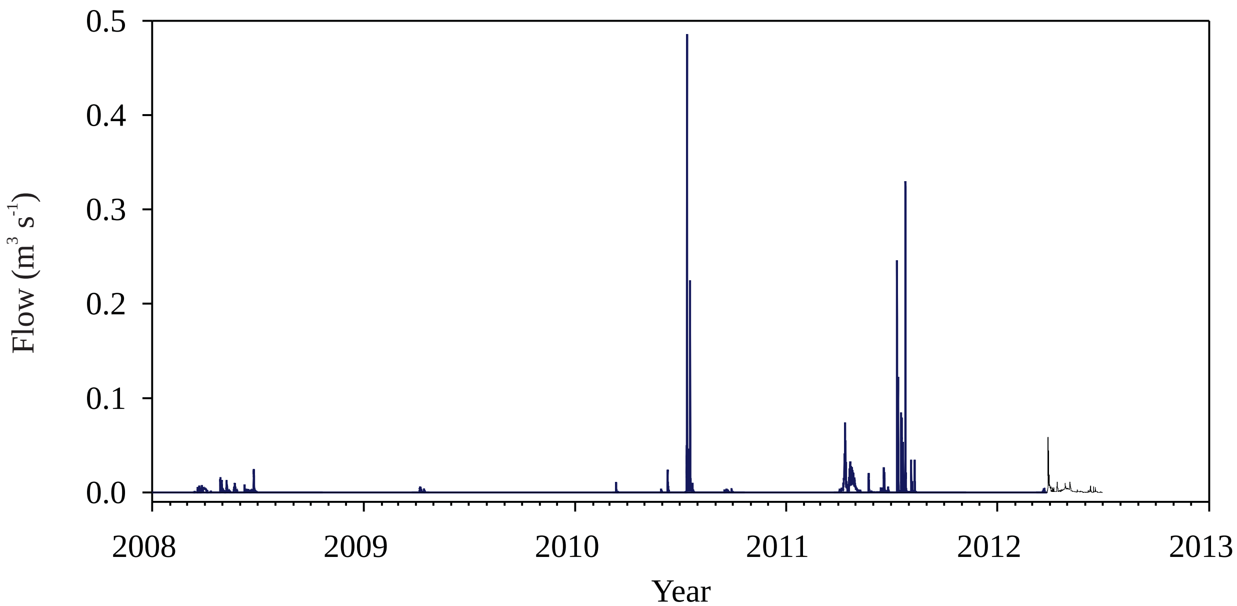

Figure 4.82. Hydrograph for the edge-of-field monitoring Station 319 at the Reference 2 site from 2008 to 2012.

average snowfall in the winter months and greater than average rainfall in the summer months (Sub-section 4.2.2), and this explains the rainfall-dominated annual flow in 2010. For the other 3 yr, the distribution was approximately equal between snowmelt- and runoff-generated runoff (Table 4.98).

Water quality. Average concentrations for all N parameters, TP, TDP, and Cl were higher during snowmelt than rainfall runoff at Station 319 (Table 4.99). For example, TN was nearly three-fold higher and TP was 1.8-fold higher in snowmelt runoff. Average concentrations of PP, EC, and pH were similar between the two runoff events; whereas, concentrations of TSS and *E. coli* were higher in rainfall events.

Total N was composed mostly (67%) of NO_3-N and NH_3-N in snowmelt runoff on average; whereas, in rainfall runoff, TN was composed mostly (73%) of ON (Table 4.99). However, there were exceptions. In 2010 and 2011, snowmelt runoff had a majority of TN in the form of ON, and in 2012, a majority of TN was in the form of NO_3-N. In 2008, 2009, and 2012, TN and NO_3-N concentrations were relatively high at or near the start of runoff and then generally decreased with time (Figure 4.83a). In 2010 and 2011, TN and NO_3-N concentrations were more consistent and no large peaks occurred compared to the other 3 yr. The highest average concentrations of TN, ON, NO_3-N, NH_3-N, Cl, and EC were observed in 2009 snowmelt (Table 4.99). Flow occurred for only a 10-d period in 2009 (Figure 4.82). Perhaps if flow had continued for a longer period and/or rainfall runoff had also occurred in 2009, the average concentrations would have been less. Manure was applied in fall 2008 and this likely contributed to higher concentrations in the snowmelt runoff in 2009. The concentrations of TP and TDP were also high in 2009 compared to 2008 and most other years. On the other hand, soil extractable N and STP were not affected to any extent by the manure application (Table 4.95). This suggests that a single application of manure can have a

Table 4.99. Average concentration water quality parameters in runoff at Station 319 at the Reference 2 site from 2008 to 2012.[z]

		TN	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS	Cl	*E. coli*	EC	
Year	n	-------------				(mg L^{-1})				-------------	(mpn 100 mL^{-1})	(µS cm^{-1})	pH
							Snowmelt						
2008	16	12.4	3.85	8.46	0.04	0.43	0.30	0.11	31	na	28	697	7.96
2009	6	44.8	7.65	34.6	0.68	1.14	1.00	0.14	4	80.5	10	1159	8.07
2010	4	2.64	2.43	0.15	0.03	1.43	1.29	0.14	9	9.03	3	257	7.66
2011	31	2.53	1.55	0.95	0.04	0.26	0.23	0.03	2	15.4	1	549	8.00
2012	13	10.0	3.42	6.09	0.31	0.99	0.82	0.17	34	20.7	14	667	7.75
All	70	9.80	3.00	6.46	0.14	0.58	0.49	0.09	15	23.4	10	640	7.93
							Rainfall						
2008	9	3.50	3.30	0.07	0.11	0.15	0.13	0.02	2	na[y]	189	863	8.04
2010	25	2.55	2.28	0.20	0.05	0.42	0.38	0.04	7	10.2	215	655	8.21
2011	25	3.39	2.54	0.80	0.04	0.37	0.19	0.18	125	11.9	839	694	8.25
2012	7	5.70	1.53	4.29	0.03	0.10	0.05	0.05	35	11.3	108	799	8.31
All	66	3.34	2.44	0.84	0.05	0.33	0.24	0.09	54	11.1	430	714	8.21

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids, Cl = chloride, *E. coli* = *Escherichia coli*, EC = electrical conductivity, pH = potential hydrogen.
[y] na = not available. Chloride was added late in July 2008.

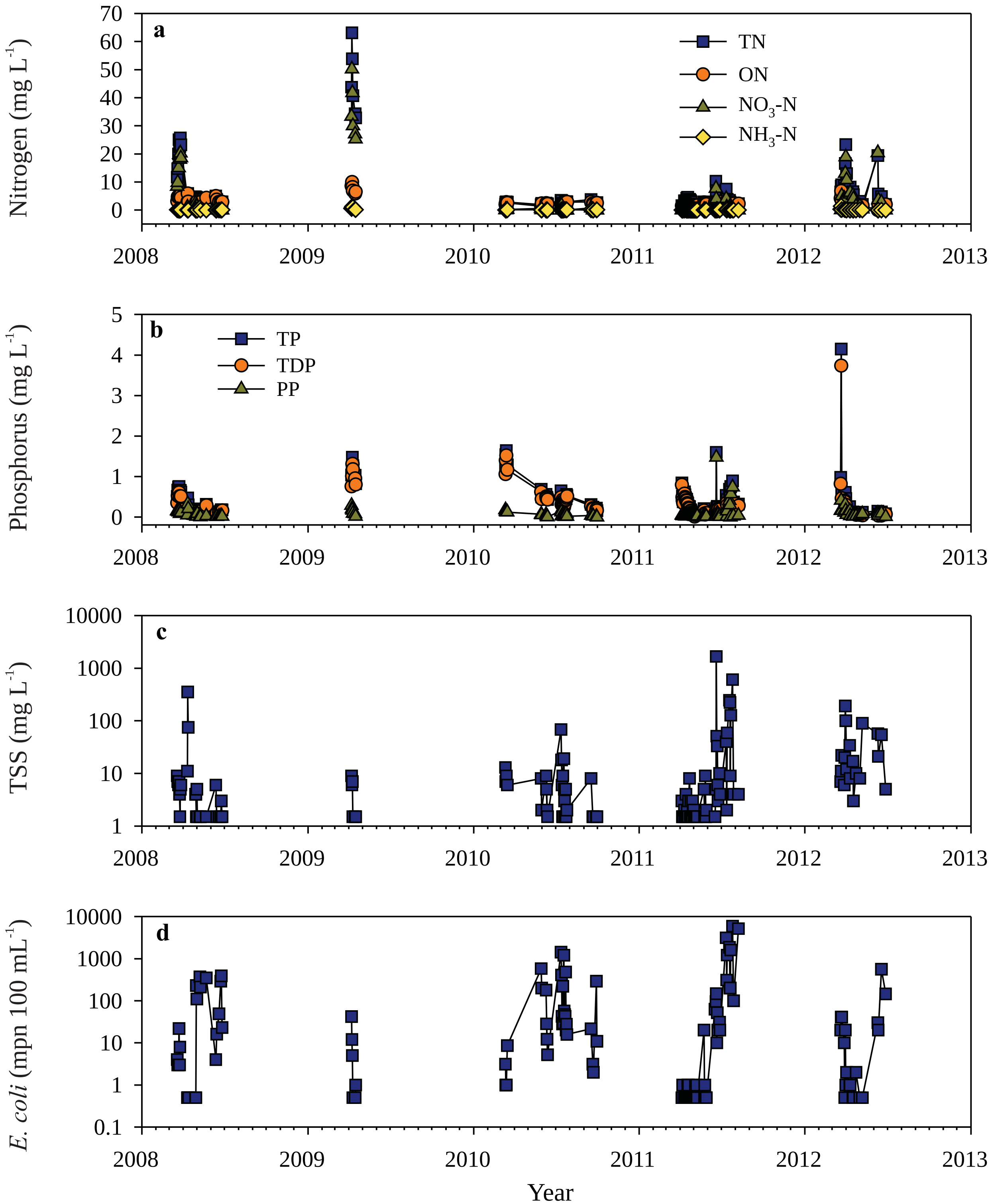

Figure 4.83. Concentrations of (a) nitrogen, (b) phosphorus, (c) total suspended solids (TSS), and (d) *Escherichia coli* (*E. coli*) at the Reference 2 site edge-of-field Station 319 from 2008 to 2012.

measurable effect on runoff water quality in the short term (i.e., one season); whereas, soil nutrient status is relatively unchanged. Manure applied more often is likely required to result in a measurable change in soil nutrients.

Total dissolved P accounted for a majority of the TP in snowmelt (84%) and rainfall (73%) runoff events on average (Table 4.99). Although during rainfall runoff in 2011 and 2012, TDP and PP had similar values. Annually, the concentrations of TP and TDP were generally highest at or shortly after the start of runoff and then decreased with time (Figure 4.83b). Annual maximum TP concentrations ranged from 0.75 mg L^{-1} in 2008 to 3.74 mg L^{-1} in 2012. As already indicated, the majority of the TP was in the form of TDP. These two parameters were highly correlated (r = 0.94, P <0.0001). An exception occurred in 2011 when a maximum peak concentration of 1.6 mg L^{-1} TP occurred on June 20, and 92% of the TP was accounted for by PP (Figure 4.83b). Also in July 2011, PP accounted for 58 to 83% of TP on four sampling days. This corresponded to peak concentrations of TSS of 1660 mg L^{-1} on June 20 and 127 to 605 mg L^{-1} on the four days in July (Figure 4.83c). The higher concentrations of PP and TSS in June and July 2011 were caused by the tillage of the 4-ha sub-division in spring 2011 and spring 2012 immediately adjacent to Station 319 (Figure 4.84a). The soil surface was exposed and subject to erosion, which lead to higher TSS and PP concentrations in runoff water. The average concentrations of TSS were also elevated in 2012 (Table 4.99, Figure 4.83c). Prior to June 2011, TSS concentrations were generally low (i.e., <10 mg L^{-1}) with a few exceptions (Figure 4.83c).

The average concentration of *E. coli* was similar among most years during rainfall, except in 2011, which had a higher average value (Table 4.99 and Figure 4.83d). The high average in 2011 was caused by a few samples with values greater than 3000 mpn 100 mL^{-1} (Figure 4.83d). The application of manure in fall 2008 did not have a noticeable effect on *E. coli* concentration in 2009.

Figure 4.84. The tilled sub-division next to Station 319 at the Reference 2 site (a) on June 22, 2011 and (b) on April 16, 2012.

Table 4.100. Annual loads of nutrients and total suspended solids in runoff at the Reference 2 site from 2008 to 2012.

Year	TN [z]	ON	NO_3-N	NH_3-N	TP	TDP	PP	TSS
	($kg\ yr^{-1}$)							
2008	118	47.7	68.9	0.89	3.97	3.29	0.67	55.6
2009	47.8	7.85	37.1	0.82	1.19	1.04	0.15	4.61
2010	75.5	51.5	22.5	0.93	12.1	9.69	2.35	461
2011	197	115	77.5	2.92	26.9	14.7	12.2	8106
2012	167	42.8	122	1.90	6.20	4.03	2.17	1053

[z] TN = total nitrogen, ON = organic nitrogen, NO_3-N = nitrate nitrogen, NH_3-N = ammonia nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, PP = particulate phosphorus, TSS = total suspended solids.

Annual loads of nutrients and TSS were generally highest in 2011 and lowest in 2009 compared to the other years (Table 4.100). This reflected that these two years had the highest and lowest annual flows, respectively (Table 4.98). The one exception was for NO_3-N, which had the highest load in 2012 and the lowest load in 2010. The average concentration of NO_3-N was relatively high in 2012 and relatively low in 2010 during snowmelt and rainfall events (Table 4.99). Plus, the NO_3-N average concentration was very high in snowmelt runoff in 2009.

4.13.4 Conclusions

- Soil extractable N and P concentrations were not excessive at this site, and this was expected for a cropped field that has received no or very little manure. Therefore, this field was not considered a high risk for nutrient loss in terms of soil nutrient status.
- The single manure application in fall 2008 caused a small increase in the concentration of NH_4-N. Extractable NO_3-N and STP were not affected by the application of manure.
- Compared to soil, runoff water was more sensitive to the single application of manure with increased concentrations of TN, ON, NO_3-N, NH_4-N, TP, TDP, Cl, and EC.
- The application of commercial fertilizer in spring 2011 had no significant effect on the average concentrations of NO_3-N, NH_4-N, and STP between the pre- and post-seeding samples from the top 15-cm soil layer. This was likely due to the relatively low amount of N and P fertilizer applied in spring 2011.
- Annual flow ranged from 980 $m^3\ yr^{-1}$ in 2009 to 57,766 $m^3\ yr^{-1}$ in 2011, with an 5-yr average of nearly 23,500 $m^3\ yr^{-1}$. Annual flow was largely driven by the amount of annual precipitation.
- In some years, groundwater discharge also contributed to flow during the rainfall periods. However, the contribution was not quantified.
- In 2009, all flow was caused by snowmelt; whereas, rainfall caused nearly all of the flow in 2010. The distribution was approximately equal between snowmelt- and rainfall-generated runoff in the other three study years.

- Average concentrations for all N parameters, TP, TDP, and Cl were higher during snowmelt than rainfall runoff. Average concentrations of PP and EC and pH were similar between the two runoff events; whereas, concentrations of TSS and *E. coli* were higher in rainfall events.
- Total N was composed mostly (67%) of NO_3-N and NH_3-N on average in snowmelt runoff; whereas, in rainfall runoff, TN was composed mostly (73%) of ON.
- Total dissolved P accounted for a majority of the TP in snowmelt (84%) and rainfall (73%) runoff events.
- Annually, the concentrations of TP and TDP were generally highest at or shortly after the start of runoff and then decreased with time. Total P and TDP were highly correlated.
- The tillage of a 4-ha area to create a sub-division adjacent to the monitoring station in spring 2011 caused an increase in the loss of PP and TSS in 2011 and 2012.
- Annual loads of nutrients and TSS were mainly influenced by annual flow. For most parameters, the largest loads were in 2011, which had the largest annual flow, and the smallest loads were in 2009, which had the smallest annual flow.