Section 2 Battersea Regional Transect Study

2.1 Introduction

2.1.1 Background

The Regional Transect Study in the Battersea area in southern Alberta builds upon previous work conducted in the 1990's and early 2000's by Rodvang *et al.* (1998, 2002). Site locations and methods were generally consistent with the historical work in order to compare groundwater quality between the 1990's and the current study. However, some changes in site locations and methods were required as outlined below. Groundwater sampling of the regional transect addresses Objective 1 (Section 1) to determine changes in groundwater quality in the Battersea area with time.

2.1.2 Stratigraphy of the Battersea Area

The stratigraphy of the Battersea area has previously been described by Rodvang *et al.* (2002). In summary, the Battersea area can be divided into two physiographic regions: (1) a bedrock high (Blacksprig Ridge) in the west underlain by Bearpaw Shale bedrock with thin unconsolidated sediments overlying the bedrock, and (2) a lacustrine plain in the east with thicker unconsolidated sediments ranging in thickness from 40 to 100 m overlying bedrock of the Oldman Formation. The unconsolidated sediment, which overlies bedrock in both regions, consists of glacial till overlain by fine- to coarse-grained glacio-lacustrine deposits.

The wells examined in the current study are in the lacustrine plain region of the Battersea area. In the lacustrine plain, the surficial lithology is divided into two groups: (1) glacial till that is overlain by up to 15 m of glacio-lacustrine plastic silty clay in the western portion of the plain, and (2) glacial till that is overlain by up to 27 m of coarse- to fine-grained sand overlying fine-grained lacustrine material in the eastern portion of the plain.

The coarse-grained lacustrine material in the eastern portion of the lacustrine plain is an unconfined aquifer with an area of approximately 900 ha in a rough triangle shape between Iron Springs and the Little Bow and Oldman rivers (Figure 2.1). This unconfined aquifer has been used as a water supply by farms in the area since 1920 (Rodvang *et al.* 2002). A buried aquifer was identified by Rodvang *et al.* (2002) immediately west of the unconfined aquifer. The buried aquifer extends from Keho Lake to Picture Butte south to the Oldman River near Lethbridge (Figure 2.2).

The wells in the Battersea area were initially divided into 11 geochemical groups based on location and soil type but were subsequently divided into six statistically-relevant groups as follows (Table 2.1, Rodvang *et al.* 2002):

- 1) <u>L</u>ethbridge Northern Irrigation District (<u>L</u>NID) <u>C</u>oarse <u>S</u>and (LCS, which was oxidized sand at a manure study plot).
- 2) Other Sand (OS, which included all oxidized sand sites not on the LCS site).
- 3) <u>R</u>educed sediments (R, which included all reduced geochemical groups: reduced sand. reduced medium lacustrine, and reduced till and clay).
- 4) <u>Shallow Till and Clay (STC, which included shallow till and clay and shallow medium lacustrine not on the LFC site).</u>
- 5) <u>Deep Till and Clay</u> (DTC, which included deep till and clay at all sites and deep medium lacustrine sites).
- 6) <u>LNID Fine Clay</u> (LFC, which was oxidized fine lacustrine sediment at a manure study plot).



Figure 2.1. Approximate thickness of the surficial aquifer in the Battersea area (adapted from Rodvang *et al.* 2002). The numbered red triangles indicate the location of historical groundwater well nests.



Figure 2.2. Approximate thickness and depth of the buried aquifer in the Battersea area (adapted from Rodvang *et al.* 2002). The numbered black triangles show the location of historical groundwater well nests.

2.2 Methods

2.2.1 Weather Data

The Iron Springs weather station (latitude 49° 54' 2", longitude 112° 44' 24", elevation 893 m) is located within the Battersea area (Fig. 2.1). Annual weather data (2009 to 2011) from this site were obtained from the Irrigation Management Climate Information Network (ARD 2010). In addition, the 30-yr average (1971 to 2000) values were obtained from the Lethbridge Canada Department of Agriculture (CDA; now Agriculture and Agri-Food Canada) weather station (latitude 49° 41' 42", longitude 112° 46' 3", elevation 910 m) because of the lack of historical data from the Iron Springs weather station (Environment Canada 2011).

Table 2.1. Summary of geochemical and statistical groupings (adapted from Rodvang et al. 2002).					
	Statistical	Geochemical		Depth	
Formation	group ^z	group	Description of geochemical group	(m)	
Coarse	1. LCS	LCS	<u>LC</u> <u>S</u> and: oxidized sand on the LC ^y site	<7.4	
Lacustrine	2. OS	OS	Other Sand: oxidized sand not on the LC site	<7.5	
	3. R	RS	<u>R</u> educed <u>S</u> and	8 – 19	
Medium	4. STC	SML	Shallow Medium Lacustrine: oxidized medium	<8.5	
Lacustrine			lacustrine where tritium was detected.		
	5. DTC	DML	Deep Medium Lacustrine: oxidized medium	5 - 8	
			lacustrine where tritium was not detected.		
	3. R	RML	<u>R</u> educed <u>M</u> edium <u>L</u> acustrine	5 - 20	
Till and Fine	6. LFC	LFC	<u>LF</u> <u>C</u> lay: oxidized fine lacustrine above 5 m on	<5	
Lacustrine			the LF ^y site plot.		
	4. STC	STC	Shallow Till and Clay: oxidized till and fine	<5	
			lacustrine above 5 m and not on the LF site.		
	5. DTC	DTC	Deep Till and Clay: oxidized till and fine	5 - 12	
			lacustrine below 6 m, on and off the LF site.		
	3. R	RTC	<u>Reduced Till and Clay: reduced till and fine</u>	3 – 75	
			lacustrine.		
Buried		BA	Buried Aquifer: reduced inter-till sand and gravel.	36 - 66	
Aquifer					

^z LCS = \underline{L} ethbridge Northern Irrigation District <u>c</u>ourse <u>s</u>and; OS = <u>o</u>ther <u>s</u>and; R = <u>r</u>educed sediments; STC =

shallow till and clay; DTC = deep till and clay; and LFC = Lethbridge Northern Irrigation District fine clay. ^y Two small plot research sites, which were less than 100 by 100 m in size. One was on a coarse-textured soil (LC) and the other on a fine-textured soil (LF). Research was conducted on the plots from 1993 to 2001 (Olson et al. 2009).

2.2.2 Regional Transect Site Description and Instrumentation

The historical wells described by Rodvang *et al.* (1998, 2002) included a total of 115 wells in 22 nests along a transect (Figure 2.3), which were installed in 1993 and 1994 (Appendix 1). A nest typically consisted of one water table well and one-to-seven piezometers with screens at various depths. The current Regional Transect Study used 12 historical wells that were located at 11 different nests (Appendix 1). Five historical wells could not be reactivated due to damage; thus, new replacement wells were installed in 2010 (Appendices 1 and 2). Additionally, six new wells were installed at five of the original nests to give a total of 23 wells in 11 nests (Appendix 2).

Transect sites, from LB2 to LB19 (Figure 2.3), were selected to represent a cross-section of geologic, hydrogeologic, and anthropogenic conditions within the area. Geological conditions ranged from fine- to coarse-grained soils. Hydrogeological conditions differed from the upgradient (northwest) to the downgradient (southeast), where groundwater discharges into the Oldman and Little Bow rivers. Wells were located next to cultivated fields, confined feeding operations, and pasture land. Often, wells were installed adjacent to road allowances to allow for easy access and to minimize the potential for damage from farm equipment.

Installation details of the historical wells were previously reported by Rodvang *et al.* (1998, 2002). Installation of historical well replacements and new wells was completed in February, March, and December 2010, and November 2011. Borehole drilling and well installation was completed utilizing a C-1150 or C-72 truck mounted drill rig equipped with solid stem or hollow stem augers. A lithologic/borehole log was recorded for boreholes instrumented in 2010 and 2011. Lithologic logs were only recorded for the deepest borehole when two or more wells were instrumented in a nest.

Water table wells and piezometers were constructed using schedule 40 PVC pipe with a nominal diameter of 50.8 mm. Water table wells were constructed with screens 1.5 to 5.0 m in length. Piezometers were constructed with screens of 0.5 m to 1.0 m in length. Wells were completed with a stickup extending approximately 0.3 m above ground surface and covered with a steel-case protector. Sand was packed around the wells from the end of the borehole to a minimum of 0.1 m above the top of the screen. Bentonite clay was used to backfill from the top of the sand pack to the soil surface. Information on the construction details of the new wells is included in the borehole logs (Appendix 3).



Figure 2.3. Historical (Rodvang *et al.* 1998, 2002) and new groundwater regional transect sites in the Battersea area. Active wells are monitored in the current study.

Site LB2

There is one nest along the southwest boundary of the quarter section at site LB2. There are a total of five wells in the nest, which were installed in 1993 and 1994 (Appendix 1). Only one water table well, LB2-1, was monitored in the current study (2009 and 2010). The water table at the site was not influenced by anthropogenic sources, including agricultural activities, or recent contributions from the ground surface (Rodvang *et al.* 2002). Monitoring of this site was discontinued in 2011 but may be re-activated in subsequent years.

Surface topography surrounding the quarter section is higher in elevation than east of the quarter section. The area is on the eastern flank of a bedrock high. A Lethbridge Northern Irrigation District (LNID) canal runs from west to east directly south of the site with an access road separating the canal bank on the south edge from the nest of wells on the north edge. Cropland on the northern half of the quarter section is irrigated with a wheel move. The LNID office is directly south of the quarter section with farmsteads in the vicinity of the site. No permanent manure storage facilities are located on the quarter section.

Site LB4 contains one nest, which includes a water table well and two piezometers. Three wells (LB4-2, LB4-4, LB4-5) were installed in 1993 and 1994 in the southeast corner of the quarter section near an old farmstead (Appendix 4). The historical wells were unserviceable for monitoring; thus, three new replacement wells (LB4-2x, LB4-4x, LB4-5x) were installed in February 2010 (Appendices 2 and 3). The new wells were instrumented in the southeast corner of the quarter section and are approximately 150 to 200 m northeast of the historical nest.

The site is east of a high elevation ridge and west of a surface topographic divide (Rodvang *et al.* 2002). Cropland on the quarter section is irrigated with a center pivot. A farmstead with a small feedlot is immediately east, with a horse pasture to the south. Manure has been stockpiled in a horse/calf pasture just south of the nest of wells.

Site LB6

At Site LB6, there is one nest along the east boundary of the quarter section with two new wells (a water table well and a piezometer; LB6-6x and LB6-7, respectively) that were monitored (Appendices 2, 3, and 4). A total of six wells were installed at the site during the historical study (Appendices 1 and 4); however, four of the six wells were decommissioned. The two remaining historical wells, both piezometers, were not used in the current study. The new wells were installed in December 2010 next to the historical nest.

Surface topography surrounding the quarter section is relatively flat; however, surface water accumulates in a low area in the northeast corner of the quarter section when the area receives excess precipitation. Cropland on the quarter section is irrigated with a center pivot, and there is an acreage on the east boundary, immediately north of the nest. Irrigated cropland exists to the north, east, and west of the quarter section with a homestead directly south of the quarter section. No permanent manure storage facilities are located on the quarter section, and manure was not stockpiled on the quarter section from 2009 to 2011. A manure-rate study was previously conducted on a portion of the quarter section (Rodvang *et al.* 1998, Olson *et al.* 2009).

Site LB7

At Site LB7, there is one historical nest with a total of seven wells that were installed in 1994. The nest lies in a shelterbelt along the north boundary of the farmstead on the quarter section, next to the gravel road on the west side of the quarter section (Appendix 4). Only LB7-2, the water table well, was monitored (Appendices 1 and 2).

Surface topography gently slopes from north to south, and surface water accumulates in the tree line along the north boundary of the farmstead. The Battersea Drain also runs in an irregular pattern across the quarter section from the southwest to northeast. Crop land on the quarter section is irrigated with a wheel move irrigation system. Farm buildings are present to the southwest of the quarter section, with cropland to the north, east, and south. A large dairy operation is on the west side of the adjacent gravel road. There are no permanent manure storage facilities on Site LB7.

At Site LB9, there is one nest in the northwest corner of the quarter section. There are 9 wells in the nest; however, only two of the wells were used in the current study. Seven of the wells were installed in 1993 and 1994, and one(LB9-6) has been decomissioned (Appendices 1 and 4). Of the historical wells, only LB9-2, the water table well, was monitored (Appendix 2). One deep (LB9-8) and two shallow (LB9-9, LB9-10) piezometers were installed next to the historical nest in December 2010 and November 2011, respectively (Appendices 2 and 3). Monitoring of LB9-8 began in February 2011, while the other two piezometers will be monitored in subsequent years.

Surface topography in the area is relatively level, and any low lying areas in the quarter section have been modified to allow for farming of the entire quarter section. The quarter section is irrigated with a center pivot. The Battersea Drain is approximately 400 m north of the quarter section. Farmland surrounds the quarter section in all directions. There are no permanent manure storage facilities on the quarter section or in the immediate vicinity.

Site LB11

There is one nest at Site LB11 in the northwest corner of the quarter section along a homestead access road. Five wells were installed in 1993 and 1994 (Appendices 1 and 4). Only the water table well, LB11-4, was monitored (Appendix 2).

Surface topography is gently undulating, and the site is located on the crest of the Oldman River Valley (Figure 2.3). Highway 845 is approximately 300 m west of the wells. The quarter section and surrounding land consists of pasture land. There are no permanent manure storage facilities on the quarter section or in the immediate vicinity.

Site LB13

There is one nest of five wells at Site LB13 in the southeast corner of the quarter section (Figure 2.3). Of the five wells at Site LB13, four are historical wells installed in 1994 (Appendices 1 and 2). A deep piezometer, LB13-5, was installed next to the historical nest in 2010 (Appendices 2 and 3). All five wells (LB13-1, -2, -3, -4, -5) were monitored and sampled at this location in the current study. The water table well, LB13-4, was damaged in December 2011. The historical well will need to be decommissioned and a replacement water table well instrumented in 2012.

Surface topography in the area is undulating. An irrigation canal runs east to west along the southern boundary of the quarter section, and the quarter section is irrigated with a pivot system. Manure is applied on the fields near this site, and it was part of a manure-rate study conducted from 1993 to 2001 (Rodvang *et al.* 1998, Olson *et al.* 2009).

Site LB13 is part of Field B in the Field-scale Manure Spreading Study and is described further in Section 3 of this report.

Site LB18 was located in the southwest corner of the quarter section. Of the five wells at the site, three were monitored, including a water table well (LB18-1x) and two piezometers (LB18-4, LB18-5) installed in February 2010 (Appendix 2). The two historical wells in the nest, one water table well (LB18-1) and one piezometer installed in 1994, were not monitored (Appendices 1 and 2). The new water table well (LB18-1x) was instrumented because the historical water table well (LB18-1) was thought to be a piezometer. Subsequent discussion of the water table well at Site LB18 refers to the new water table well, LB18-1x. The historical water table well, LB18-1, will be monitored in subsequent years.

Surface topography in the area is undulating. An irrigation canal runs east to west along the southern boundary of the quarter section, and the quarter section is irrigated with a pivot system. There are some low lying areas in the center of the quarter section, and the nest is north of some irrigation ponds. Manure is applied on the fields near this site, and it was part of a manure-rate study conducted from 1993 to 2001 (Rodvang *et al.* 1998, Olson *et al.* 2009).

Site LB18 is part of Field B in the Field-scale Manure Spreading Study and is described further in Section 3 of this report.

Site LB19

There is one nest with four wells at Site LB19 in the centre of the quarter section along an access trail at the top end of a natural draw. Two wells were installed at Site LB19 in the 1990's (LB19-1 and LB19-2, Appendix 1). Two piezometers were installed next to the historical nest in December 2010 and November 2011 (Appendices 2 and 3). The historical water table well (LB19-2) and the piezometer installed in December 2010 (LB19-3) were monitored. The piezometer installed in November 2011 will be used in subsequent years of the study.

Surface topography in the area is gently undulating. The quarter section is on the crest of the Oldman River Valley and is the furthest east site in the study area (Figure 2.3). The Site is surrounded by native prairie range land, which is grazed by beef cattle. A gas plant is approximately 600 m east of the wells.

Site LB21

There is one nest at Site LB21 in the northeast corner of the quarter section. Two historical wells, including one water table well and one piezometer, were installed in the 1990's (Appendix 1). The historical water table well, LB21-2, and piezometer, LB21-1, were monitored for the Regional Transect Study. There are three other nests with a total of four wells in the northwest, southwest, and southeast corners of the quarter section, but these wells were not monitored for the Regional Transect Study and are described in Section 3 as part of the Field-scale Manure Spreading Study.

The quarter section was consolidated with the southeast quarter section into a single halfsection field with a common pivot irrigation system. Surface topography in the area is gently undulating. All natural surface water features on the section have been physically altered by the landowner to allow for farming practices.

Site LB22

There is one nest at Site LB22 along the east boundary of the quarter section. The nest consists of three wells installed in the 1990s in the tree line on the south side of an acreage (Appendices 1 and 4). The water table well, LB22-3, was the only well sampled at this site (Appendix 2).

Surface topography in the area is gently undulating, and a large wetland area lies along the south boundary of the quarter section. The site is east of the Little Bow River. The quarter section is irrigated with a center pivot, with crop land to the south and west. A side-roll irrigation system is used to the south of the acreage. Agriculture and Agri-Food Canada maintains test plots to the south of the wells.

2.2.3 Soil Core Sampling and Analysis

Soil cores samples were obtained during drilling of new wells. A soil core sample was collected from each incremental foot depth from the deepest well completed at each field site (LB6-7, LB9-8, LB13-5, LB18-5, and LB19-3) in February and December (Figure 2.4). A soil core (7 to 8 cm long) for isotope analysis was removed below each foot depth mark starting at 1 ft (0.30 m) below ground surface (Figure 2.4). In addition, a soil core (7 to 8 cm long) for physical and chemical analysis was removed above every other foot mark depth starting at 2 ft (0.61 m) below the ground surface. Samples were collected to a depth of about 20 m. The samples were analyzed by the University of Saskatchewan (U of S) for physical and isotope parameters. The physical parameters included gravimetric and volumetric moisture contents and bulk density.

For the physical parameters, each core sample was cut into two pieces. The first piece was used to measure gravimetric water content and bulk density, and the second piece was used to measure volumetric water content. Each core sample was dipped in hot wax. Samples for volumetric water content analysis were placed in a known volume of water in a graduated cylinder to determine the volume of water displaced by the sample. Samples for bulk density analysis were attached to the under-hook of an electronic precision balance and weighed while suspended in water. The wax was then removed from the samples, which were dried for 48 h in an oven ranging from 60 to 80 °C.

For isotope analysis, core samples were double bagged in Zip Lock bags, and the inner bag containing the sample was inflated with dry air. Dry air was produced using compressed air flowing through a tube containing Drierite. Samples were equilibrated with head space/dry air for a minimum of 3 d. Samples were then analyzed using Off-Access Integrated Cavity Output Laser Spectroscopy (OA-ICOS). Two different standards that isotopically bracket the core samples were used. Standards were prepared by filling Zip Lock bags with 10 mL of water with known isotopic values for deuterium (²H) and oxygen-18 (¹⁸O). Standards were double bagged,



Figure 2.4. Soil sampling profiles for various boreholes in 2010 and 2011. Soil cores were collected for isotope (black bars) and chemical (grey bars) analyses. Cores collected for chemical analyses were also used for analysis of physical parameters. Cores collected in February 2010 were only analyzed for chemical parameters. Cores collected from LB13-5 and LB18-5 are illustrated in Section 3.2.4 (Figure 3.5).

filled with dry air, and left to equilibrate for a minimum of 30 min. One standard was run for every two core samples. Measurements were made every 10 s. Standards were left for a minimum 3-min run time. Pore water samples from the cores were extracted by dehydrating the cavity with dry air until the water vapor concentration was less than 800 ppm. Data points 8 to 10 were repeated following each sample analysis. Data were corrected against the Standard Mean Ocean Water (SMOW) line to determine actual isotopic values of the liquid pore water for each core.

After the samples were analyzed for physical parameters by the U of S, the samples (i.e., samples collected above every other foot mark starting at 2 ft below the ground surface) were analyzed for chemical parameters and particle size distribution by Alberta Agriculture and Rural Development (ARD). Samples were air dried and ground to pass through a 2-mm sieve. The time between when the samples were collected and dried was a minimum of 6 mo, and samples were stored at room temperature during this period. Samples were analyzed for the following parameters (Appendix 5):

- pH (saturated paste extract)
- Electrical conductivity (EC) (saturated paste extract)
- Anions: nitrate nitrogen (NO₃⁻-N), nitrite nitrogen (NO₂⁻-N), chloride (Cl⁻) bicarbonate (HCO₃⁻), carbonate (CO₃²⁻), sulphate sulphur (SO₄²⁻-S), and phosphate phosphorus (PO₄³⁻-P) (saturated paste extract)
- Cations: ammonium nitrogen (NH₄⁺-N), calcium (Ca²⁺), magnesium (Mg²⁺), potassium (K⁺), and sodium (Na⁺) (saturated paste extract)
- Extractable NO₃⁻-N and NH₄⁺-N (10:1 ratio of 2M potassium chloride (KCl):soil)
- Extractable PO₄³⁻-P (modified Kelowna extraction)
- Particle size analysis (hydrometer method)
- Gravimetric moisture content (oven dried)
- Sodium absorption ratio (calculated)

Because the above samples were stored wet at room temperature for a minimum of 6 mo, there was concern about the accuracy of the NO_3 -N analysis. Therefore, a second set of boreholes were drilled adjacent to LB6-7, LB9-8, and LB19-3 in November 2011. A soil core (15 cm long) was collected above every foot mark depth starting at 1 ft (0.30 m). Samples were collected to a depth of about 10 m. The samples were immediately air dried and ground to pass through a 2-mm sieve. Samples from every other foot were analyzed for nutrients and anions by ARD. As well, a soil core (7 to 8 cm long) was collected below every foot mark depth starting at 1 ft (0.30 m). These samples were analyzed for isotopes by the U of S by first squeezing pore water from the soil cores and then analyzing the water.

Core samples were also collected using disturbed sampling from LB4-2x and LB4-4x in February 2010. Core segments 30- to 50-cm long were collected from the bottom of every 1.5-m incremental layer (Figure 2.4). Drilling was completed using a hollow stem auger. Chemical analyses were the same as for the deep borehole samples (Appendix 5).

2.2.4 Point Velocity Probe Instrumentation

Point velocity probe (PVP) stands were installed next to three nests in August 2011. Two PVP stands were installed at Site LB9, one PVP stand at Site LB18, and one PVP stand at Site LB19. The purpose of the PVPs is to measure groundwater velocity direction and magnitude *in situ* at the centimetre scale (Delvin *et al.* 2009, Schilling *et al.* 2011). The PVP stands were installed by Ernco Environmental Drilling and Coring Inc. using a Geoprobe system with EC probe under the direction of the Universities of Kansas and Saskatoon. A total of six PVP units were installed between the two stands at Site LB9: three at PVP8 next to LB9-1 and three at PVP9 next to LB9-2 (Appendix 2). One PVP stand, with two PVP units, was installed next to LB18-4. Three PVP units were installed at the stand at LB19 next to LB19-2 (Appendix 2). Depths were estimated to intercept wet collapsible sand layers. Preliminary tests were conducted in November 2011 with the University of Kansas to determine if borehole settling had occurred and instrumentation was working. These data are not part of the Regional Transect Study but will be discussed in subsequent reports.

2.2.5 Well Elevation Surveying

The horizontal location of the wells was obtained using a survey grade, handheld global positioning system (GPS) unit. Groundwater wells at the transect sites were surveyed for geodetic elevations in October 2010 and November 2011 by Brown Okamura and Associates Ltd. of Lethbridge, Alberta. Vertical elevations were determined relative to mean sea level.

2.2.6 Well Development

Well development was initiated shortly after the wells were installed and prior to the collection of the first water samples. Well development consisted of removing water from the wells using a polyethylene bailer (1 L), Waterra pump, or purge pump. A minimum of two well volumes were removed from each well in order to remove fine particles from around the well screen, improve the rate of water moving into the well, and stabilize the aquifer to produce samples representative of the aquifer. Well development was carried out for a longer period for some wells in the sandier portions of the study area until water turbidity was visibly reduced.

2.2.7 Groundwater Monitoring

Groundwater Elevation

Groundwater elevations were determined using manual measurements, pressure transducer measurements, and well survey measurements. The depth to groundwater was measured by lowering a sounding tape into each water table well and piezometer and recording the depth to water from a mark placed on the inside of the well casing. Groundwater measurements during 2010 and 2011 were conducted prior to each purging and sampling event, and additional measurements were made on a monthly basis in 2011when water sampling was changed to a quarterly basis (Appendix 6). Measurements were recorded on field sheets for subsequent entry into the electronic database.

Pressure transducers (Levelogger[®] Gold, Model 3001, Solinst Canada Ltd.) were used to record changes in absolute pressure (i.e., water column pressure plus barometric pressure) in 4-h intervals in order to determine water height. Pressure transducers were installed at LB5a-1, LB7-2, LB8a-1, LB11-4, LB13-4, LB21-2, and LB22-3 in the second half of 2010. All pressure transducers were changed to log at 15-min intervals in December 2011. Two pressure transducers (LB4-2x and LB21-2) were used to measure atmospheric pressure, which was used to calculate groundwater elevations.

The levelogger data were reviewed based on the manual measurements, and the data and height of the pressure transducer were adjusted as required to match the manual measurements. Contour plots were prepared using ArcGIS 10.0 (ArcGIS Desktop Release 10.0 © 1999-2010. ESRI Inc., Redlands, California, United States). Contours were prepared with grids generated using the Spline method of interpolation. Since the elevation was unknown for surface water in the Battersea Drain, interpolation barriers were used to account for the change in landscape and groundwater flow paths around the Battersea Drain.

Groundwater Purging

Prior to groundwater sampling, the wells were purged using a Waterra pump or polyethylene bailer (1 L). Wells were purged until three well volumes of water had been removed or until the well was dry (piezometers were not purged below the well screen). Purged water was disposed of adjacent to the wells. All equipment was thoroughly rinsed with deionized water and dried with a paper towel between wells.

If a pressure transducer was present in a well, it was removed after the water table depth was measured but prior to well purging. The total well depth was measured after the pressure transducer, if present, was removed. Total well depth was measured to examine whether the effective screen interval had changed as a result of silting in the well.

Groundwater Sampling and Analysis

Groundwater samples were collected from selected wells from monthly to bi-monthly in 2010 (Appendix 6). Groundwater sampling was changed to quarterly sampling in 2011 as it was determined that an adequate baseline had been established and seasonal trends could still be observed.

Groundwater samples were collected 7 to 14 d after purging, depending on the recovery rate of the water in the well. Samples were collected from the top of the water column in the well using a polyethylene bailer. Sample bottles were triple rinsed with sample water before filling. One, 1-L high density polyethylene bottle was filled with as little headspace as possible for chemical analysis, and one, 1-L high density polyethylene bottle was filled for isotopic analysis. In August 2011, one, 250-mL glass bottle was filled with as little headspace as possible for total organic carbon analysis. After collection, samples were placed in coolers with ice packs or frozen 1-L bottles of water. Samples for chemical analysis were submitted to the ARD laboratory in Lethbridge on the same day as sampling. Samples for isotopic analysis were shipped in coolers without ice to the U of S.

In-field measurements of pH, electrical conductivity (EC), dissolved oxygen (DO), and temperature were measured in a spare sample bottle using the first bail from the well [WTW multi 3400i and 3500i with Oxical-cx (DO and EC) and SenTix 41 (pH) probes, Global Water Instrumentation, Inc.]. Field alkalinity measurements were also conducted during the August 2011 sampling event (Alkalinity Test Kit, Model AL-DT, HACH Company).

Groundwater samples were analyzed in the ARD laboratory for nutrients, anions, and cations (Appendix 7). Nutrients included TN, NO₃⁻-N, NO₂⁻-N, ammonia nitrogen (NH₃-N), TP, total dissolved phosphorus (TDP), and $PO_4^{3^-}$ -P; cations included Ca^{2+} , Mg^{2+} , Na^+ , and K^+ ; and anions included $SO_4^{2^-}$, Cl⁻, HCO₃⁻, and CO₃^{2^-}. Other parameters analyzed included dissolved total carbon (D-TC), dissolved non-purgeable organic carbon (D-NPOC), and dissolved inorganic carbon (D-IC). Chemical analyses were completed by the lab within 24 h of sample collection for nutrients and anions, with TN analyzed as soon as the samples were received, and TDP and TP analyzed within 7 d. Samples for cation analysis were filtered, preserved with nitric acid (HNO₃), and analyzed within 7 d. Dissolved total carbon and dissolved non-purgeable organic carbon analyses were completed within 2 wk of sample collection.

Groundwater samples were analyzed at the U of S Isotope Laboratory for ²H and ¹⁸O. Isotopic data 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. Duplicate groundwater samples were collected at a rate of 10% of samples collected per day and submitted for analysis as part of the quality control/quality assurance protocol. Relative percent difference was examined for duplicate samples. Quality control data are not presented in this report.

Changes in methods and method detection limits between historical and current data (Appendix 7) are not expected to influence any trends in the data as the methods were considered comparable (Ki Au 2011, personal communication, ARD).

2.2.8 Hydraulic Conductivity Testing

Hydraulic conductivity data for historical wells were obtained from Rodvang *et al.* (2002). Hydraulic conductivity testing for wells installed in 2010 and 2011 will be carried out in 2012.

2.2.9 Geochemical Groupings

Given that the current study did not sample the LCS or LFC (Subsection 2.2.1) sites, only four geochemical categories were used to group sample data collected from 2009 to 2011. The geochemical groups used were other sand (OS), shallow till and clay (STC), deep oxidized till and clay (DTC), and reduced sediments (R) (Table 2.1). A total of 23 wells were used in the geochemical groupings (Table 2.2). Geochemical water types were compared between the historical and current groupings.

Regional Transect Study.		
Well name	Well type	Geochemical group ^z
LB2-1	Water table	DTC
LB4-2x	Water table	STC
LB4-4x	Piezometer	R
LB4-5x	Piezometer	R
LB6-6	Water table	STC
LB6-7	Piezometer	R
LB7-2 ^y	Water table	STC
LB9-2 ^y	Water table	OS
LB9-8	Piezometer	R
LB11-4 ^y	Water table	OS
LB13-1	Piezometer	R
LB13-2	Piezometer	R
LB13-3 ^y	Piezometer	OS
LB13-4 ^y	Water table	OS
LB13-5	Piezometer	R
LB18-1x ^{y,x}	Water table	STC
LB18-4	Piezometer	R
LB18-5	Piezometer	R
LB19-2 ^y	Water table	OS
LB19-3	Piezometer	R
LB21-1	Piezometer	R
LB21-2 ^y	Water table	OS
LB22-3 ^y	Water table	OS

Table 2.2. Water table wells and piezometers in the four geochemical groupings used in the Regional Transect Study.

^z STC = shallow till and clay; DTC = deep till and clay; OS = other sand; R = reduced sediments.

^y Used for comparisons between historical and current data.

^x Historical LB18-1 was compared with current LB18-1x, which was re-drilled to match the historical well.

2.2.10 Comparisons to Historical Data

Historical and current data from regional transect wells were compared to assess groundwater quality changes with time in the Battersea area. Comparisons were only made for wells screened in the shallow oxidized zone. Wells in deep oxidized till and fine textured lacustrine sediments were not included in the comparisons, as groundwater greater than 6 m below the ground surface was not highly vulnerable to contamination (Rodvang *et al.* 2002). Wells screened in reduced sediment were not included in the comparisons as historical analyses suggested denitrification removed NO₃⁻-N from reduced sediments (Rodvang *et al.* 2002). Nine wells initially used by Rodvang *et al.* (2002) were used for the comparisons. Six wells located in oxidized coarse fluvial

sediments (LB9-2, LB13-3, LB13-4, LB19-2, LB21-2, LB22-3), two wells located in medium lacustrine sediments (LB11-4, LB18-1x), and one well located in oxidized fine lacustrine sediments (LB7-2) were used. The wells fit into the other sand, LC sand, and shallow till and clay geochemical groups that Rodvang *et al.* (2002) used in mixed model and regression analyses with data collected from 1994 to 2001.

Data were separated into historical (1994 to 2001) and current (2009 to 2011) sampling periods. Data were compared by well rather than by geochemical groupings as the majority of the nine wells used for historical comparisons were in the OS group (Table 2.2).

2.2.11 Statistical Analysis

Basic summary statistics were computed using SYSTAT 13 (Version 13.00.05. SYSTAT Software, Inc. 2009, Chicago, Illinois, United States). The minimum measurable detection limit (MMDL) was used when reporting concentration ranges (i.e., minimum concentrations detected), but a value of half the MMDL was used in mean and median calculations. Minimum method detection limits for each parameter are listed in Appendix 7.

Historical and current data from regional transect wells were compared using the Proc Mixed procedure in SAS 9.2 with variance components as the variance structure and repeated measures, lsmeans, and pdiff options (@2002-2008 by SAS Institute Inc., Cary, North Carolina, United States). A significance level (*P*) of <0.05 was used.

2.3 Results and Discussion

2.3.1 Weather

Total annual precipitation received in 2009, 2010, and 2011 was 384, 451, and 391 mm, respectively. Total annual precipitation was above the 30-yr (1971 to 2000) average of 365 mm for all three years. In 2009, the summer months (June, July and August) and October received above average precipitation, while other months received precipitation below the average (Figure 2.5). In contrast, 2010 and 2011 had two to three times the average precipitation in April and May. Additionally, precipitation in October 2011 was more than double the average precipitation, and July 2011 was also above the 30-yr average. Precipitation in August and September was three to seven times below average in 2011.



Figure 2.5. Monthly precipitation comparisons for the Battersea area from 2009 to 2011.

2.3.2 Stratigraphy

Stratigraphy at the wells installed in 2010 was consistent with the stratigraphy previously described in Subsection 2.1.2. Details of the lithologies encountered during drilling of each well are included with the borehole logs in Appendix 3.

2.3.3 Groundwater Elevation

Groundwater elevation results for all wells are summarized in Appendix 8. Shallow groundwater elevations were generally consistent with groundwater elevations reported by Rodvang *et al.* (2002). The flow direction was from northwest to southeast in the study area (i.e., from the bedrock high to the Oldman and Little Bow rivers) (Figure 2.6).

Water table elevations increased in the spring and early summer in response to spring runoff, spring and summer rainfall, and irrigation (Figure 2.7). Elevations declined through the fall and into the winter. Mean water table measurements ranged from approximately 1 to 3 metres below ground surface (mbgs) throughout the study area. Shallow water table elevations were similar between 2010 and 2011 (Figure 2.7, Appendix 8). The water table was 2 to 17 cm higher in 2011 than in 2010.



Figure 2.6. Shallow groundwater elevation for the Battersea transect in October 2011 (2-m contour interval; numbers represent metres above sea level; arrows indicate inferred groundwater flow direction).



Figure 2.7. Groundwater elevation in 2010 and 2011 for (a) LB7-2, (b) LB9-2, (c) LB11-4, and (d) LB22-2.

2.3.4 Groundwater Chemistry

Current Groundwater Chemistry

Chloride and NO₃⁻-N concentrations varied among the geochemical groups. Chloride concentrations ranged from the minimum measurable detection limit (MMDL) to 1096 mg L⁻¹, with a mean concentration of 104 mg L⁻¹ (Table 2.3). The mean Cl⁻ concentration was highest for the STC geochemical group. The mean Cl⁻ concentration in the DTC well was similar to the STC wells, while concentrations in the OS and R wells were three to five times lower. Nitrate N concentrations ranged from the MMDL to 144 mg L⁻¹, with a mean concentration of 27 mg L⁻¹ (Table 2.3). The mean NO₃⁻-N concentration was highest for the DTC geochemical group, followed by the STC and OS groups. Similar to Cl⁻ concentrations, the lowest NO₃⁻-N concentrations were measured in the R geochemical group.

Chloride and NO₃⁻-N concentrations in soil saturated-paste extracts measured in 2011 at well LB6-7 (which belongs to the STC group) increased with depth, reaching maximum concentrations at about 10 mbgs before decreasing with depth (Figure 2.8). Similar soil Cl⁻ profiles were observed by Rodvang *et al.* (1998) in some wells in the STC group. Elevated Cl⁻ and NO₃⁻-N concentrations in the STC wells suggest that groundwater has been impacted by land use management practices. However, it is uncertain if elevated NO₃⁻-N concentrations in some of the STC wells, as well as the DTC well, represent influences from manure application or geologic conditions.

Elevated Cl⁻ and NO₃⁻-N concentrations measured in LB2-1, the well screened in DTC, were consistent with historical measurements collected in the 1990s (Rodvang *et al.* 1998). Previous work concluded the elevated NO₃⁻-N concentrations measured in LB2-1 were of geologic origin as tritium was not detected, which is used as an indicator of recharge after 1951 (Rodvang *et al.* 1998). Additional analyses will be required in subsequent years to confirm the water table at LB2-1 is still not influenced by anthropogenic sources or recent contributions from the ground surface.

In general, groundwater quality in the Battersea area was highly mineralized, with a mean total dissolved solids (TDS) content of 1590 mg L⁻¹ (Table 2.3). Total dissolved solids concentrations were greatest in the STC and DTC geochemical groups, with mean concentrations of 3428 mg L⁻¹ and 4292 mg L⁻¹, respectively, and lowest in the OS group wells with a mean concentration of 829 mg L⁻¹.

Table 2.3. Concentrations of chloride (Cl⁻), nitrate nitrogen (NO₃⁻-N), and total dissolved solids (TDS) for geochemical groups in the Battersea area from 2009 to 2011.

		Cl			NO ₃ ⁻ -N	ſ		TDS	
Geochemical ^z	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
group (n)	(mg L ⁻¹)								
STC (4)	5	1096	256	0.05	144	33	666	7360	3428
DTC (1)	225	240	234	71	78	74	3155	4448	4292
OS (7)	5	228	67	0.05	74	23	262	1552	829
R (11)	5	182	44	0.05	82	12	346	4632	1319
All wells (23)	5	1096	104	0.05	144	26	262	7360	1580

^z STC = shallow till and clay; DTC = deep till and clay; OS = other sand; R = reduced sediments.



Figure 2.8. Chloride (Cl⁻) and nitrate nitrogen (NO₃⁻-N) concentrations in soil saturated-paste extracts at LB6-7 in December 2010.

Preliminary geochemical typing was completed on groundwater samples, using the median values of the major ions for the major geochemical groupings (Table 2.4). Results indicate that groundwater types were similar between the samples taken in the 2000 and the current study. For the STC geochemical group, sodium (Na⁺) was present in 2000 but not in 2010. For the OS group, sulphate ($SO_4^{2^-}$) was present in 2000 but not in 2010. Sulphate may be removed through reduction processes, while Na⁺ may be removed through ion exchange reactions (Appelo and Postma 1996). Additional analyses in subsequent years will refine the geochemical typing and assist with interpretations.

Table 2.4. Geochemical type	es of groundwater samples in 2000 an	d 2010.
Geochemical group ^z	2000 water type	2010 water type
STC	Mg-Na-Ca-SO ₄	$Mg-Ca-SO_4$
DTC	Ca-Mg-SO ₄	Ca-Mg-SO ₄
OS	Mg-Ca-HCO ₃ -SO ₄	Mg-Ca-HCO ₃
R	Ca-Mg-HCO ₃	Ca-Mg-HCO ₃
7		

^z STC = shallow till and clay; DTC = deep till and clay; OS = other sand; R = reduced sediments.

No consistent seasonal pattern was observed for NO_3^--N and Cl^- in most geochemical groups. Chloride and NO_3^--N concentrations fluctuated in some of the wells screened in the OS geochemical group, but there were no consistent patterns among years (Figure 2.9). Nitrate N appeared to decrease from 2009 to 2011 in a few of the OS wells. Concentrations fluctuated in 2009 and 2010 in one well screened in the STC geochemical group, and the highest concentrations in 2009 and 2010 were elevated compared to 2011 (Figure 2.10). However, sampling also decreased from every 2 wk to a quarterly basis in 2011. Data were only available for 2011 in the majority of the wells in the R geochemical group and will be assessed for annual variability in subsequent years.



Figure 2.9. Concentrations of (a) chloride (Cl⁻) and (b) nitrate nitrogen (NO₃⁻-N) in 2009 to 2011 in wells screened in the Other Sand (OS) geochemical group.



Figure 2.10. Chloride (Cl⁻) and nitrate nitrogen (NO₃⁻-N) concentrations from 2009 to 2011 in wells screened in the Shallow Till and Clay (STC) geochemical group.

Comparison to Historical Data

Four of the nine wells (LB9-2, LB13-3, LB18-1x, and LB19-2) had significantly higher Cl⁻ and NO_3^- -N concentrations during the current sampling period (2009 to 2011) compared to the historical sampling period (1994 to 2001) (Table 2.5). Three wells (LB11-4, L22-3, and LB21-2) had either significantly higher Cl⁻ or NO_3^- -N concentrations in the current sampling period, with no significant difference between the two sampling periods for the other parameter. Two wells (LB7-2 and LB13-4) had a significantly higher concentration of one parameter in the current period compared to the historical period; whereas, the opposite was true for the other parameter (i.e., significantly less concentration in the current period). Comparisons between the historical and current concentrations are discussed separately for each of the nine wells.

in the Battersea area.			
		Cl	NO ₃ ⁻ -N
Well	Sampling period	$(\text{mg } \text{L}^{-1})^{\mathbf{z}}$	$(\operatorname{mg} \operatorname{L}^{-1})^{\mathbf{z}}$
LB7-2	Historical	438.03 a	0.53 b
	Current	65.91 b	2.91 a
LB9-2	Historical	20.99 b	40.46 b
	Current	220.25 a	59.83 a
LB11-4	Historical	22.07 a	4.74 b
	Current	24.34 a	6.73 a
LB13-3	Historical	28.37 b	19.98 b
	Current	69.77 a	41.19 a
LB13-4	Historical	46.91 b	38.33 a
	Current	89.24 a	21.77 b
LB18-1x ^y	Historical	4.96 b	4.88 b
	Current	54.95 a	66.27 a
LB19-2	Historical	4.96 b	5.03 b
	Current	26.36 a	14.58 a
LB21-2	Historical	14.14 b	23.25 a
	Current	24.60 a	19.04 a
LB22-3	Historical	7.77 a	7.50 b
	Current	7.87 a	15.57 a

Table 2.5. Comparison of mean chloride (CI) and nitrate nitrogen (NO₃⁻-N) concentrations between historical (1994 to 2001) and current (2009 to 2011) groundwater samples from nine wells in the Battersea area.

^z Means for each well site comparison (i.e., historical vs. current) followed by the different letters are significantly different at $P \le 0.05$.

^y Historical LB18-1 was compared with current LB18-1x, which was re-drilled to match the historical well.

Well LB7-2

In water table well LB7-2, the current NO_3^-N values were elevated relative to historical values; whereas, Cl⁻ values were lower in the current sampling period compared to the historical period (Figure 2.11, Table 2.5). These results differ from those previously observed in other wells screened in till and fine sediments where such changes were not observed from 1994 to 2001 (Rodvang *et al.* 2002). It remains to be determined why NO_3^-N increased and Cl⁻ decreased at this site from the historical period to the current period.





Well LB9-2

In LB9-2, Cl⁻ and NO₃⁻-N concentrations were significantly elevated by an order of magnitude relative to historical values (Figure 2.12, Table 2.5). Rodvang *et al.* (2002) did not observe any changes in NO₃⁻-N or Cl⁻ concentrations in LB9-2 from 1995 to 2001. Chloride and NO₃⁻-N concentrations in soil saturated-paste extracts from borehole LB9-8 in November 2011 increased with depth to approximately 9 and 5 mbgs, respectively, before decreasing with depth (Figure 2.13). Nitrate N was not detected below 7.5 mbgs, which is where reduced sediments were observed during drilling (Appendix 3). It is uncertain whether the elevated Cl⁻ and NO₃⁻-N concentrations with depth in the soil are a result of manure management practices or a combination of agricultural and natural sources. Although Cl⁻ and NO₃⁻-N concentrations were higher in the current period compared to the historical period, concentrations appeared to decrease from 2009 to 2011 (Figure 2.12). Water table elevations may have influenced concentrations as the water table fluctuated seasonally as well as increased from 2009 to 2011(Appendix 8).



Figure 2.12. Concentrations of nitrate nitrogen (NO₃⁻-N) and chloride (Cl⁻) in LB9-2. Historical data are from 1995 to 2001 and the current data are from 2009 to 2011.



Figure 2.13. Chloride (Cl[°]) and nitrate nitrogen (NO₃⁻-N) concentrations in soil saturatedpaste extracts at LB9-8 in November 2011.

Well LB11-4

In LB11-4, NO₃⁻-N concentrations were elevated relative to historical concentrations; however, Cl⁻ concentrations were similar between the current and historical periods (Figure 2.14, Table 2.5). Generally, NO₃⁻-N concentrations were similar to concentrations measured from 1999 to 2001. Rodvang *et al.* (2002) found increasing NO₃⁻-N and Cl⁻ concentrations in LB11-4 from 1994 to 2001 (slope=0.09 and 0.3 and p=0.008 and 0.004, respectively). Although current Cl⁻ concentrations were not significantly higher than historical concentrations, Cl⁻ tended to increase from 2009 through 2011. Site LB11 is in native rangeland near the Oldman River and is well separated from cultivated fields. It was previously suggested lateral groundwater transport from other fields was responsible for the NO₃⁻-N and Cl⁻ measured at site LB11 (Rodvang *et al.* 2002).



Figure 2.14. Concentrations of nitrate nitrogen (NO₃⁻-N) and chloride (Cl⁻) in LB11-4. Historical data are from 1994 to 2001 and the current data are from 2009 to 2011.

Well LB13-3

Chloride and NO_3 ⁻N concentrations were generally elevated by two fold at LB13-3 compared to those observed from 1995 to 2001, with the exception of June 2001 (Table 2.5, Figure 2.15). Rodvang *et al.* (2002) did not find a significant increase in NO_3 ⁻N and Cl⁻ concentrations from 1995 to 2001. It is uncertain why the concentrations were elevated in June 2001 compared to the rest of the historical data set. Nitrate N concentrations in 2010 and 2011 were variable and decreased from 2010 to early 2011. Chloride concentration was also higher in 2010 than in 2011.



Figure 2.15. Concentrations of nitrate nitrogen (NO₃⁻-N) and chloride (Cl⁻) in LB13-3. Historical data are from 1995 to 2001 and the current data are from 2010 to 2011.

Well LB13-4

Chloride concentrations in LB13-4 were higher, while NO_3^- -N concentrations were lower compared to historical values (1995 to 2001) (Figure 2.16, Table 2.5). In comparison, Cl⁻ and NO_3^- -N concentrations remained relatively stable in this well from 1995 to 2001 (Rodvang *et al.* 2002). The elevated Cl⁻ concentrations and decreased NO_3^- -N concentrations in LB13-4 will be investigated further in subsequent years.



Figure 2.16. Concentrations of nitrate nitrogen (NO₃⁻-N) and chloride (Cl⁻) in LB13-4. Historical data are from 1995 to 2001 and the current data are from 2009 to 2011.

Well LB18-1x

In LB18-1x, current Cl⁻ and NO₃⁻N concentrations were significantly elevated by more than an order of magnitude relative to historical values (Figure 2.17, Table 2.5). Rodvang *et al.* (2002) did not look at trends in this well from 1994 to 2001, although NO₃⁻N concentrations appeared elevated in 2001 compared to the previous years. Chloride and NO₃⁻N concentrations in soil saturated-paste extracts were elevated near the soil surface and decreased with depth to approximately 5 mbgs, where concentrations were generally below the MMDL (Figure 2.18). The elevated concentrations in the shallow water table well suggest leaching has occurred from the ground surface (where higher concentrations are observed) and that groundwater has been impacted by land use management (including manure management) in the Battersea area. Fine unoxidized sediments were observed below 5 mbgs during borehole drilling in 2010 (Appendix 3). This suggests that NO₃⁻-N leaching below 5 m may be reduced in the unoxidized zone where anoxic conditions can support denitrificaiton. Although Cl⁻ was detected in piezomters 10 (LB18-4) and 20 mbgs (LB18-5) (17 to 49 mg L⁻¹), NO₃⁻-N was generally less than the MMDL (Appendix 9).



Figure 2.17. Concentrations of nitrate nitrogen (NO₃⁻-N) and chloride (Cl⁻) in LB18-1x. Historical data are from 1994 to 2001 and the current data are from 2011.



Figure 2.18. Chloride (Cl[°]) and nitrate nitrogen (NO₃⁻-N) concentrations in soil saturatedpaste extracts at LB18-5 in 2011.

Well LB19-2

In LB19-2, NO₃⁻-N and Cl⁻ concentrations were elevated relative to historical concentrations (Figure 2.19, Table 2.5). Rodvang *et al.* (2002) also found an increasing trend in NO₃⁻-N and Cl⁻ concentrations in LB19-2 from 1996 to 2001 (slope=0.12 and 0.19 and p=0.008 and 0.006, respectively). Similar to site LB11, LB19 is in native rangeland near the Oldman River and well separated from cultivated fields. It was suggested lateral groundwater transport from other fields was responsible for the NO₃⁻-N and Cl⁻ measured at LB19 (Rodvang *et al.* 2002).



Figure 2.19. Concentrations of nitrate nitrogen (NO₃⁻-N) and chloride (Cl⁻) in LB19-2. Historical data are from 1996 to 2001 and the current data are from 2010 to 2011.

Chloride concentration was significantly higher in the current period compared to the historical period in LB21-2 (Table 2.5). Although mean NO_3^- -N concentrations were not statistically different between the two study periods, NO_3^- -N appeared to increase from 1996 to 2000 and decrease from 2009 to 2011 (Figure 2.20). A similar pattern was observed for Cl⁻. Rodvang *et al.* (2002) found a significant increase in NO_3^- -N and Cl⁻ from 1996 to 2001 (slope=0.41 and 0.31 and p=0.002 and 0.005, respectively). As with LB9-2, water table elevation at LB21-2 increased from 2009 to 2011 with seasonal highs in June (Appendix 8).



Figure 2.20. Concentrations of nitrate nitrogen (NO₃⁻-N) and chloride (Cl⁻) in LB21-2. Historical data are from 1996 to 2001 and the current data are from 2009 to 2011.

Well LB22-3

The mean NO₃⁻-N concentration increased from the historical period to the current period in LB22-3 (Table 2.5). Chloride concentrations appeared elevated in groundwater samples taken between May 2009 and July 2010 (Figure 2.21); however, mean concentrations of samples taken throughout the year were not different between the two periods. Rodvang *et al.* (2002) did not report a significant trend in NO₃⁻-N or Cl⁻ concentrations from 1996 to 2001. Although NO₃⁻-N concentrations were elevated compared to the historical study, NO₃⁻-N values appeared to decrease from 2009 to 2011 (Figure 2.21). It is uncertain why NO₃⁻-N decreased from 2009 to 2011. Water table elevation increased from 2009 to 2011 by approximately 1 m (Appendix 8), and this may have played a role in diluting nitrate-rich groundwater or created conditions favorable for removal of NO₃⁻-N.



Figure 2.21. Concentrations of nitrate nitrogen (NO₃⁻-N) and chloride (Cl⁻) in LB22-3. Historical data are from 1996 to 2001 and the current data are from 2009 to 2010.

2.4 Summary and Future Work

2.4.1 Summary

The monitoring of groundwater quality in the Battersea area from 2009 to 2011 builds upon previous work conducted in the 1990's and early 2000's. The main objective of the Battersea Regional Transect Study is to determine changes in groundwater quality with time. This study will continue from 2012 to 2015.

Field work from 2009 to 2011 included the installation of new water table wells and piezometers, re-establishment of some historical wells, water table elevation monitoring, groundwater sampling, surveying of wells, and the collection of soil samples for chemical and isotopic analyses. Transect site locations and methods were generally consistent with the historical work in order to compare groundwater quality between the two sampling periods.

Transect sites were selected to provide a representative cross section of geologic, hydrogeologic, and anthropogenic conditions within the Battersea area. Geological conditions of the selected sites ranged from fine-grained to coarse-grained soils. Hydrogeological conditions ranged from the upgradient side to the downgradient side, where groundwater discharges into the Oldman and Little Bow rivers. The various hydrogeologic conditions found within the area were represented by the different study sites. Anthropogenic conditions were represented by sites adjacent to cultivated fields, confined feeding operations, and rangeland.

Groundwater elevations measured in the current study were consistent with groundwater elevations previously measured, and the results indicated a flow direction from northwest to southeast in the area (i.e., from the bedrock high to the Oldman and Little Bow rivers). Water table elevations increased in the spring and early summer in response to spring runoff, summer rainfall, and irrigation of the fields, and then declined through the fall and into the winter.

Nitrate N and Cl⁻ concentrations from 2009 to 2011 were generally high in wells in the shallow and deep till and clay and oxidized sand, with mean NO_3^--N and Cl⁻ concentrations of 26 and 104 mg L⁻¹, respectively. These elevated concentrations suggest that groundwater impact has occurred from anthropogenic sources, likely manure management activities, within the Battersea area. In general, groundwater quality in the Battersea area was highly mineralized.

Generally, increases in NO₃⁻-N and Cl⁻ concentrations were observed in wells when compared to the historical data (1994 to 2001). Nitrate N and/or Cl⁻ concentrations significantly increased from the historical period to current monitoring period at the majority of wells in oxidized sand. The initial trends suggest that NO₃⁻-N and Cl⁻ from manure are continued to move downward into the aquifer at greater intensity. Greater water table fluctuations during the current study compared to the historical period may have moved more NO₃⁻-N and Cl⁻ into the groundwater in 2009 to 2011. Wells constructed in areas overlain by shallow till also had significant increases in NO₃⁻-N; however, varying patterns were observed for Cl⁻.

2.4.2 Future Work

The following work is planned for the Regional Transect Study:

- Groundwater monitoring and sampling will be conducted four times per year (winter, spring, summer, and fall). Monitoring frequency of some of the deeper piezometers will be reduced where the recovery in water levels between sampling has not occurred during past sampling events (e.g., LB5a-5 and LB5a-6).
- Twelve additional historical wells will be re-activated for monitoring in 2012: LB7-3, LB7-4, LB7-7, LB8-4, LB9-7, LB11-3, LB12-2, LB14-2, LB16-1, LB16-2, LB18-1, and LB22-2.
- Groundwater samples will be analyzed for additional isotopes, including tritium, deuterium, oxygen-18, nitrogen-15, and helium-3, in order to age date groundwater within the Battersea area.
- Hydraulic conductivity testing will be conducted on representative wells included in the monitoring network and groundwater velocities will be calculated.
- Preliminary tests on the point velocity probes (PVPs) instrumented at Sites LB9, LB18, and LB19 will be conducted to determine if borehole settling has occurred and then determine groundwater velocity direction and magnitude.
- Further geochemical evaluation of groundwater sample results will be conducted.
- A more detailed statistical analysis of groundwater chemistry will be completed to assess trends in groundwater quality.
- Land management information will continue to be collected. This information will include manure application timing and rates, crops planted/harvested, and irrigation application rates.
- Soil samples collected in 2011 will be analyzed. Soil sampling in the fields will be conducted in subsequent years in order to determine changes in the soil concentrations of the parameters of concern with time.
- Manure samples will be collected prior to or at the time of manure application.