

Section 3 Field-scale Manure Spreading Study

3.1 Introduction

The objective of this study is to determine the risks of manure spreading activities on groundwater quality. There are two main components: (1) field-scale groundwater monitoring and (2) field-scale nutrient budget assessment.

3.1.1 Field-scale Groundwater Monitoring

The field-scale groundwater monitoring involved the instrumentation of four quarter section fields with water table wells and piezometers around the periphery of the fields. These wells were used to determine the water table groundwater flow direction, along with deeper groundwater flow direction at the field-scale. Upgradient and downgradient concentrations of nutrients in groundwater were measured to determine if there was a detectable impact on groundwater concentration from manure application on the fields. In addition, the nested wells were used to determine vertical hydraulic gradients and to assess if field-scale application of manure is leading to increased concentrations of parameters of concern at depth.

3.1.2 Field-scale Nutrient Budget Assessment

A mass-balance budget method will be used for nitrogen (N), chloride (Cl^-), and phosphorus (P). This will be used to estimate the potential loading to groundwater of leachable N and Cl^- at the four field sites. Nutrient budgeting is a tool that can be used to determine whether nutrients are over or under applied within a given region, either at a field scale or at a large watershed scale. An over application of nutrients will cause an accumulation of nutrients in the upper soil profile. Excess nutrients not taken up by crops and removed through harvesting are subject to loss, including leaching through the soil profile and into groundwater.

The four field sites selected for the Field-scale Manure Spreading Study have a history of solid beef cattle manure application from local confined feeding operations. Preliminary sampling of the top 15-cm soil layer in December 2010 showed that the average ($n=5$) soil-test phosphorus (STP) concentration among the fields ranged from 98 to 699 mg kg^{-1} , which is well above the agronomic threshold of about 60 mg kg^{-1} . Generally, once a soil is at or above the agronomic threshold, the application of additional P will not result in a yield response (Howard 2006) and will be in excess of crop requirements. The STP results suggest that manure P has been over applied relative to crop removal and has caused an accumulation in soil P in these fields. However, this does not necessarily mean that N has been over applied. The nutrient balance in manure is generally not the same as what crops require. The main concern is with the balance between N and P. Usually, if manure is applied based on the N requirement of crops, P will be over applied. The annual application of solid cattle manure based on the N requirements of irrigated barely was shown to prevent the accumulation of soil extractable nitrate nitrogen ($\text{NO}_3\text{-N}$) but caused STP to increase from 12 to 121 mg kg^{-1} in 6 yr (Olson *et al.* 2010). The average annual application rate of N-based manure in the study was 31.6 Mg ha^{-1} on a wet-

weight basis at 39% average moisture content. Other field studies in southern Alberta have shown that higher manure application rates (40 to 180 Mg ha⁻¹) resulted in even greater accumulation of STP as well as N accumulation and net NO₃⁻-N leaching (Chang and Entz 1996; Chang and Janzen 1996; Olson *et al.* 2009). It was estimated that an annual application of 14 Mg ha⁻¹, or less, of cattle manure under irrigation on a clay loam soil would prevent NO₃⁻-N leaching (Chang and Entz 1996).

A simple N and P budget was previously used to estimate the amount of land required for manure application in the Lethbridge Northern Irrigation District portion of the Country of Lethbridge, which includes the Battersea study area (Bennett and McCarley 1995). It was concluded that the entire land base of 70,800 ha would be needed to accommodate the agronomic utilization of manure N and that at least 50% more land would be needed to accommodate the agronomic utilization of manure P. Another study carried out an N and P budget in a sub-watershed (2565 ha) of the Lower Little Bow Watershed, which is northeast of the Battersea area (Bremer *et al.* 2008). The budget was based on producer survey information and several general assumptions on input and output parameters. They estimated that the sub-watershed receives a surplus of approximately 38 kg ha⁻¹ y⁻¹ of N and 5 kg ha⁻¹ y⁻¹ of P. The primary source of surplus N was from manure and fertilizer and the primary source of surplus P was from manure.

For the purposes of the current study, the mass-balance budget method for NO₃⁻-N loading will be based on the equation of Meisinger and Randall (1991):

$$N_{pl} = N_{input} - N_{output} - \Delta N_{st} \quad \text{Equation 3.1}$$

Where:

- N_{pl} is the potentially leachable total N
- N_{input} is the N entering the field to the depth of soil measurement
- N_{output} is the N leaving the field to the depth of soil measurement
- ΔN_{st} is the change in N storage in the field to the depth of soil measurement

On a field-scale basis, the following are possible fluxes for N inputs and outputs and changes in N storage within the soil profile:

N_{input} : <ul style="list-style-type: none"> crop seed manure irrigation water precipitation atmospheric depositions <hr/> fertilizer^z N fixation by legumes^y runon water^x pesticides^w 	N_{output} : <ul style="list-style-type: none"> crop harvest denitrification volatilization <hr/> runoff water^v livestock weight gain^u 	ΔN_{st} : <ul style="list-style-type: none"> inorganic N organic N <hr/> crop residue^t
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^z The study fields have a history of manure application, and it is assumed that commercial fertilizers are not applied; however, this will need to be confirmed.

^y All four fields are used to production annual crops and legumes are not part of the rotation.

^x It is assumed that runon water is negligible or non-existent.

^w It is assumed that contributions from pesticides is negligible.

^v It is assumed that runoff water is negligible or non-existent.

^u Livestock are not grazed on the study fields.

^t It is assumed that crop residue will remain reasonably constant and can be ignored.

The bolded parameters above the horizontal lines will be used or further investigated for possible use in the mass-balance calculations; whereas, the parameters below the lines, although they may contribute in other situations, will not be considered in this study. Information on the agricultural operations conducted at each field site will be collected to develop a land-use history. Management information will also be collected annually during the span of the project.

The Cl⁻ and P budgets will be calculated similar to the N budget. Similar to NO₃⁻-N, Cl⁻ is water soluble and can readily leach through soil with the downward movement of water. Chloride is relatively inert in the soil and can serve as a good tracer for soil water movement (Chang *et al.* 1991; White and Broadley 2001; Dyck *et al.* 2003). Phosphorus is much less mobile in soil, but when applied at high rates, usually from manure application, surface soils can become saturated and result in P leaching through soil (Whalen and Chang 2001; Olson *et al.* 2010). Because Cl⁻ and P do not have gaseous phases, budget calculations will be simpler compared to N.

The field-scale nutrient budget assessments will be conducted in future years and discussed in further detail in subsequent reports.

3.2 Methods

3.2.1 Weather

The weather station in the Battersea area is located at Iron Springs (latitude 49° 54' 2", longitude 112° 44' 24", elevation 893 m). Annual weather data (2009 to 2011) from this site were obtained from the Irrigation Management Climate Information Network (ARD 2010). See Subsection 2.2.1 for further details.

3.2.2 Field Description and Previous Investigations

Four, quarter-section fields were selected to represent typical geological conditions in the Battersea area:

- Field A: A fine-grained field site, adjacent to LB5a.
- Field B: A transition between the fine-grained and coarse-grained environment, adjacent to LB13 and LB18.
- Fields C/D: Coarse-grained field sites, adjacent to LB20 and LB21.

Field A is about 2km NE of Picture Butte, Field B is about 10km E of Picture Butte, and Fields C and D are approximately 12km E of Picture Butte.

All four fields have been under crop production for many years and are currently irrigated with pivot irrigation systems. The fields also have a history of beef manure application. Field A is irrigated using a pivot irrigation system with a corner arm. An irrigation canal is immediately south of Field B. Fields C and D are adjacent to each other and are managed as a single field with a common pivot irrigation system.

Long-term and extensive manure application was a requirement in selection of the field sites. The presence of tritium, as reported by Rodvang *et al.* (1998, 2002), was also taken into consideration when selecting field sites as tritium detection is an indication of more recent groundwater recharge (i.e., post 1951). Groundwater originating from more recent recharge is more likely affected by anthropogenic activities than less recent recharge. In addition, as indicated in Subsection 3.1.2, STP concentrations at these four fields were well above the agronomic threshold, confirming that manure has been applied at rates that caused nutrient accumulation in the soil.

3.2.3 Borehole Drilling and Well Installation

Installation details of eight historical wells used in the current field-scale study has been previously reported (Rodvang *et al.* 1998, 2002) (Appendices 1 and 2). Installation of historical well replacements and new wells was completed in 2010 and 2011 and described below. 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.

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 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 chips or pellets were used to backfill from the top of the sand pack to the soil surface in most cases. For some deeper wells, a layer of cuttings was used as backfill above the lower bentonite seal, followed by a secondary bentonite seal at the surface. 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. Information on the construction details of the new wells can be found in the borehole logs (Appendix 3).

Field A

Wells at Field A include six nests or single wells located around the periphery of the field for a total of 14 wells (Figure 3.1). No historical wells existed.

Well installation commenced in February 2010 at which time six wells, identified as nest LB5a, were installed in the northeast corner of the field, which is bound by gravel roads to the north and east with an old railroad track running across the northwest corner of the quarter section. Installation included a water table well (LB5a-1) completed to a depth of 4.0 metres below ground surface (mbgs) and five piezometers (LB5a-2 to LB5a-6) with completion depths ranging from 3.0 to 20.0 mbgs (Appendices 2 and 3).

Eight additional wells were installed at Field A on February 28, 2011. The additional wells included three nests (LB5c, LB5e, and LB5f) and two individual water table wells (LB5b-1 and LB5d-1). The nests contained a water table well completed to a depth of 4.0 to 4.5 mbgs and a piezometer completed to a depth of 9.0 mbgs (Appendices 2 and 3). The individual water table wells not located in a nest were completed to depths of 4.0 mbgs (LB5b-1) and 4.5 mbgs (LB5d-1) (Appendices 2 and 3).

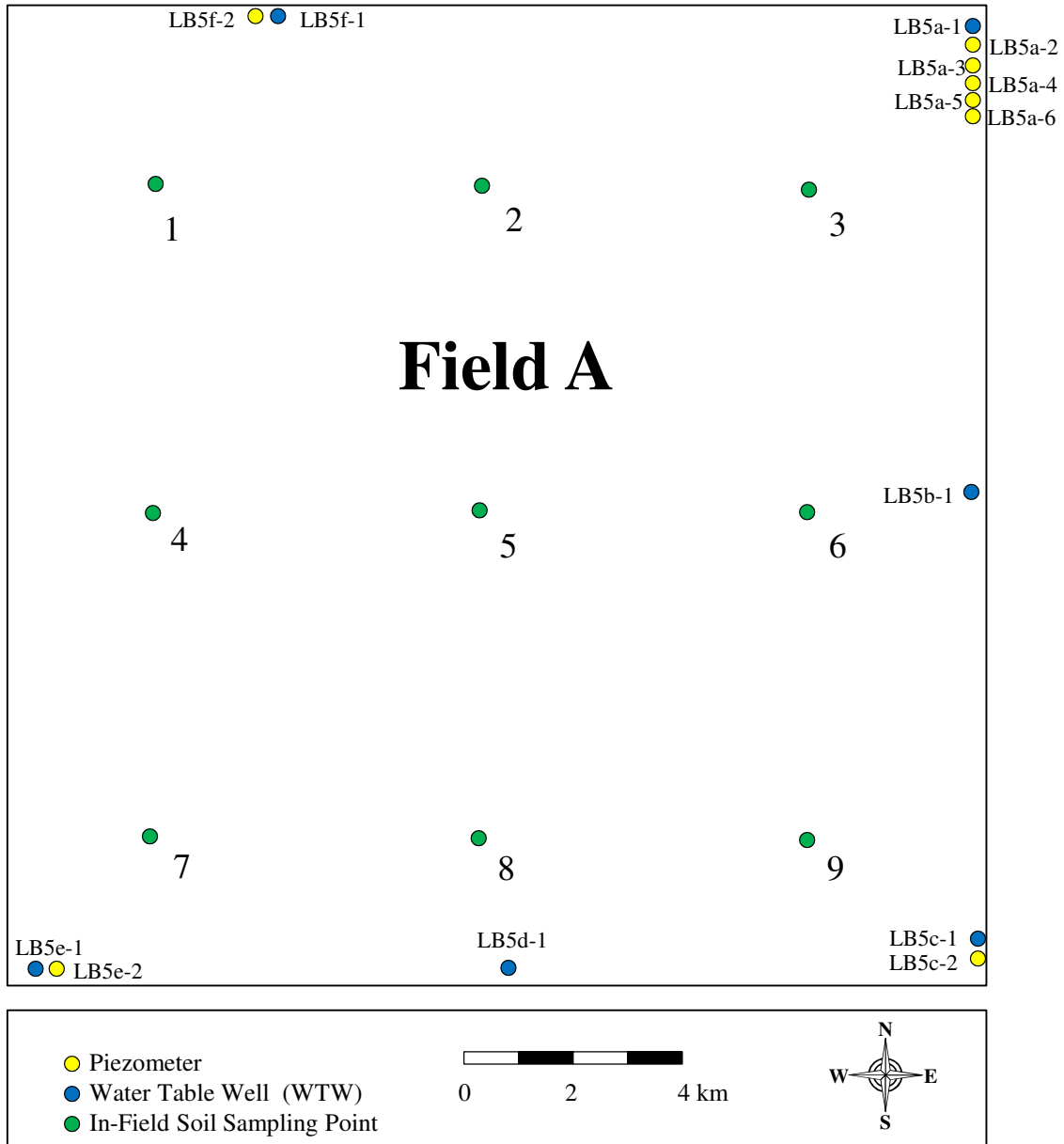


Figure 3.1. Location of groundwater wells at Field A and in-field soil sampling points taken in fall 2011.

Field B

There are 19 wells installed along the periphery of Field B. Fourteen of the nineteen wells are active (historical and new) at the site (Figure 3.2).

Two nests of wells, LB13 and LB18, were part of the historical study conducted in the area (Rodvang *et al.* 2002). Historical wells used as part of the monitoring at Field B included water table well LB13-4 and piezometers LB13-1, LB13-2, and LB13-3 (Appendix 1). Seven wells were installed along the periphery of Field B. New wells installed at these two historical nests included piezometer LB13-5, installed in February 2010 to a depth of 20.1 mbgs, piezometers LB18-4 and LB18-5, installed in December 2010 to a depth of 10.0 and 20.0 mbgs, respectively, and water table well LB18-1x, completed to a depth of 3.0 mbgs (Appendices 2 and 3). The latter replaced LB18-1, which was misidentified at the time of installation. Therefore, there are two water table wells in nest LB18. Additional wells were installed at Field B in March 2011. The additional wells included two nests (LB13c and LB13d) and three individual water table wells (LB13a-1, LB13b-1, and LB13e-1) (Figure 3.2). The nests consisted of a water table well completed to a depth of 3.0 to 4.0 mbgs and a piezometer completed to a depth of 9.7 to 10.5 mbgs (Appendices 2 and 3). The water table wells were completed to a depth of 3.0 mbgs. Three of the water table wells, LB13a-1, LB13d-1, and LB13e-1, were found to be dry (i.e., installed above the water table). In December 2011, LB13e-1 (Old LB13e-1 in Figure 3.3) was replaced with another water table well approximately 3.0 mbgs and half-way between LB13-5 and the original well, and LB13d-1 was replaced with another water table well (LB13f-1) approximately 3.0 mbgs and half-way between LB13d-1 and the old LB13e-1. Water table well LB13a-1 was not replaced.

Fields C and D

At Fields C and D, five nests and four single wells were installed around the periphery of the fields (Figure 3.3). The 17 wells used to monitor Fields C and D were a combination of historical wells and new wells installed in 2010 and 2011 (Figure 3.3). Historical wells used in the current study include LB21-1 and LB21-2, in the northeast corner of Field D.

A total of 15 new wells were installed around Fields C and D. Five wells were installed in February 2010 in the southeast corner of Field C (nest LB20) and one well at the centre pivot location (LB20a-1) near the northwest corner of Field C (Figure 3.3). The five wells installed at LB20 included a water table well (LB20-3) completed to a depth of 6.0 mbgs and four piezometers (LB20-4, LB20-5, LB20-6, and LB20-7) completed at depths ranging from 3.5 to 20.7 mbgs (Appendices 2 and 3). Additional wells were installed at Fields C and D on March 2 and 3, 2011. These included three nests (LB20b, LB20e, and LB21a) and three individual water table wells (LB20c-1, LB20d-1, and LB21b-1). The nests consisted of a water table well completed to 4.5 mbgs (LB20b-1), 4.8 mbgs (LB21a-1), or 5.0 mbgs (LB20e-1) and a piezometer completed to 9.5 mbgs (LB21a-2) or 9.7 mbgs (LB20b-2 and LB20e-2) (Appendices 2 and 3).

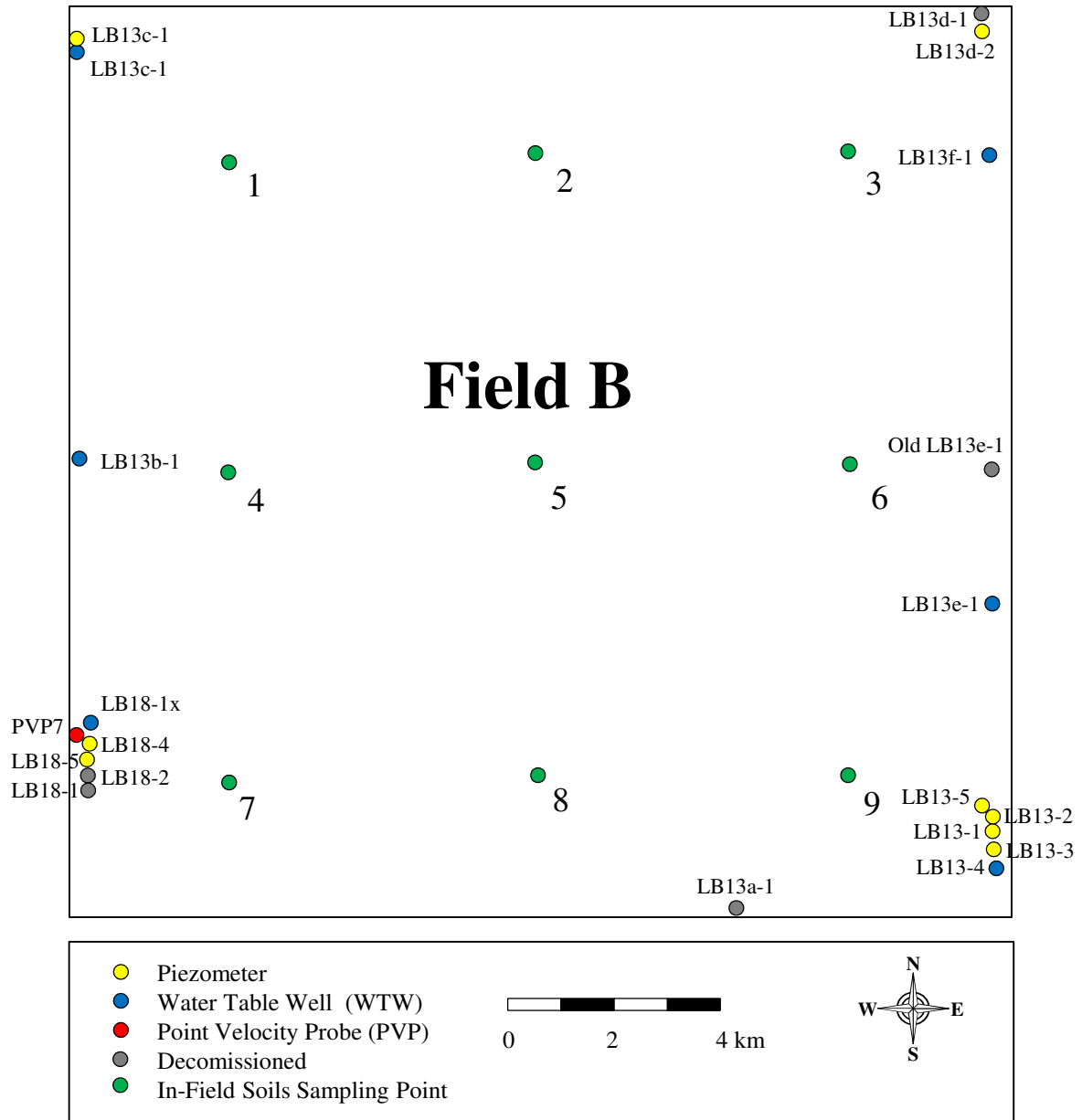


Figure 3.2. Location of groundwater wells at Field B and in-field soil sampling points taken in fall 2011.

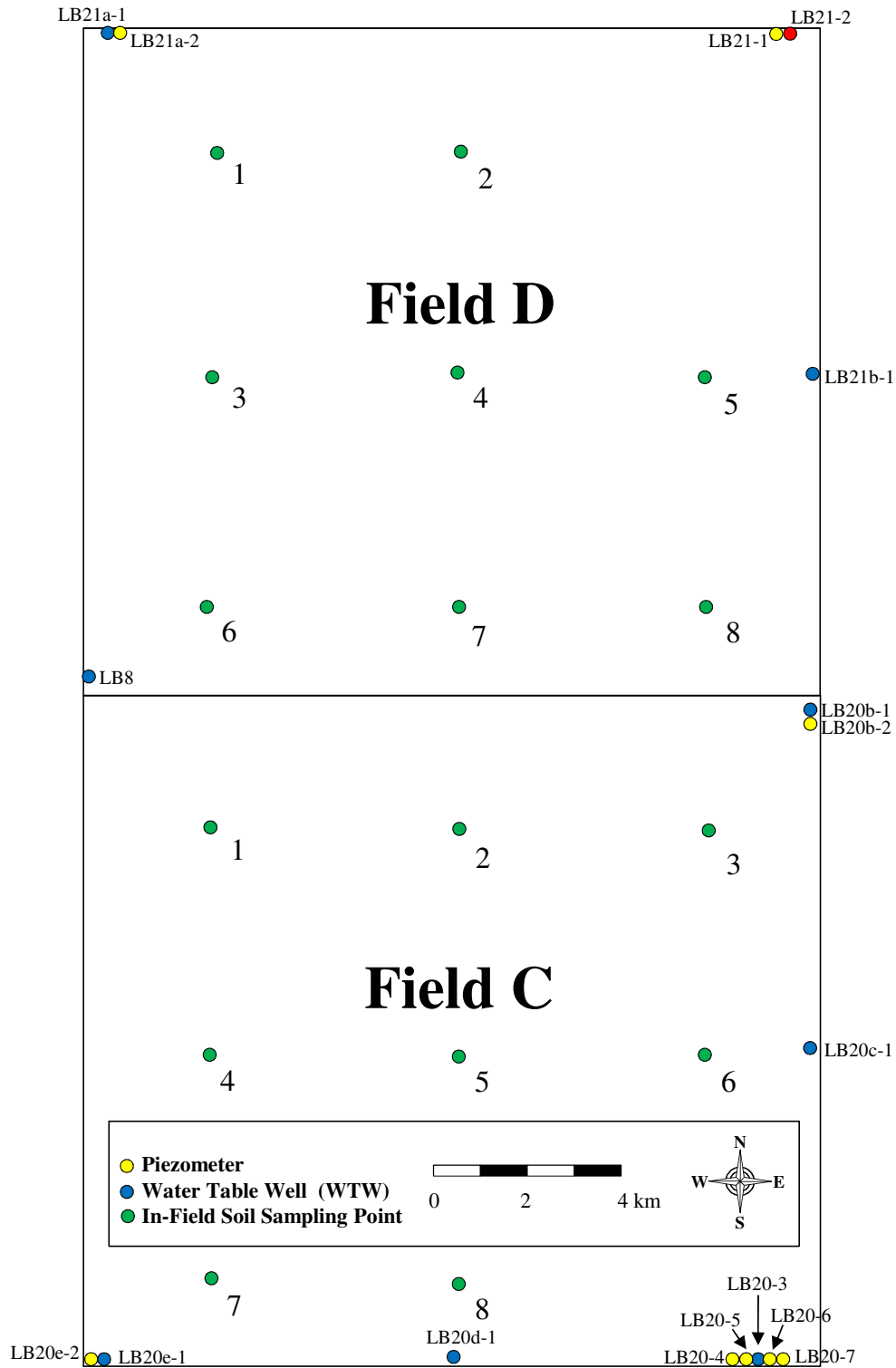


Figure 3.3. Location of groundwater wells at Fields C and D and in-field soil sampling points taken in fall 2011.

3.2.4 Soil Sampling and Analysis

Well Borehole Soil Samples

Core samples were collected during borehole drilling at Fields A, B, C, and D in 2010 and 2011.

An 8- to 15-cm core was collected from the centre of each incremental foot depth (0.3 m) of the deepest well completed at each nest in February (LB5a-6, LB13-5) and March 2010 (LB20-7) (Figure 3.4). These cores were sent to the University of Saskatchewan (U of S) where each core was split into two: one used for isotope analysis and the other used for physical analysis (gravimetric moisture, volumetric moisture, and bulk density), and later for chemical analysis. Samples were collected to a depth of about 20 m.

For LB18-5, 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 in December 2010 (Figure 3.4). 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.

After the cores from the above wells were analyzed for physical properties by the U of S, these samples were sent to Alberta Agriculture and Rural Development (ARD) for chemical analysis. The samples were dried and ground to pass through a 2-mm sieve. It was later discovered that these samples had been stored wet for a minimum of 6 mo at room temperature, and as a result, there was concern about the accuracy of the chemical analysis, particularly for $\text{NO}_3\text{-N}$. Therefore, new soil samples were collected by re-drilling boreholes within 1 m of the original wells in February 2011 (LB5a-6 and LB13-5), September 2011 (LB20-7), and November 2011 (LB18-5). During the re-drilling, a soil core (15 cm long) was collected above every foot mark depth starting at 1 ft (0.30 m) (Figure 3.4). Samples were collected to a depth of about 6 m (LB5a-6, LB13-5, and LB20-7) and 10 m (LB18-5). The samples were immediately air dried and ground to pass through a 2-mm sieve. Samples collected every other foot were analyzed for nutrients and anions by ARD. In addition, for the LB18-5 re-drill, a soil core (7 to 8 cm long) was collected below every foot mark depth starting at 1 ft (0.30 m) (Figure 3.5). These latter 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 from all other nests installed at Fields A, B, C, and D in 2010 and 2011, either from the deepest piezometer or from the water table well if only one well was installed, using disturbed sampling (i.e., the structure of the soil was altered during sampling so that structural properties of the samples were no longer representative of *in situ* conditions). Core segments 30- to 50-cm long were collected from the bottom of every 1.5-m incremental layer (Figure 3.4, Table 3.1). Drilling was completed at 16 wells using a hollow stem auger. Total well depths ranged from 3 to 9.7 m.

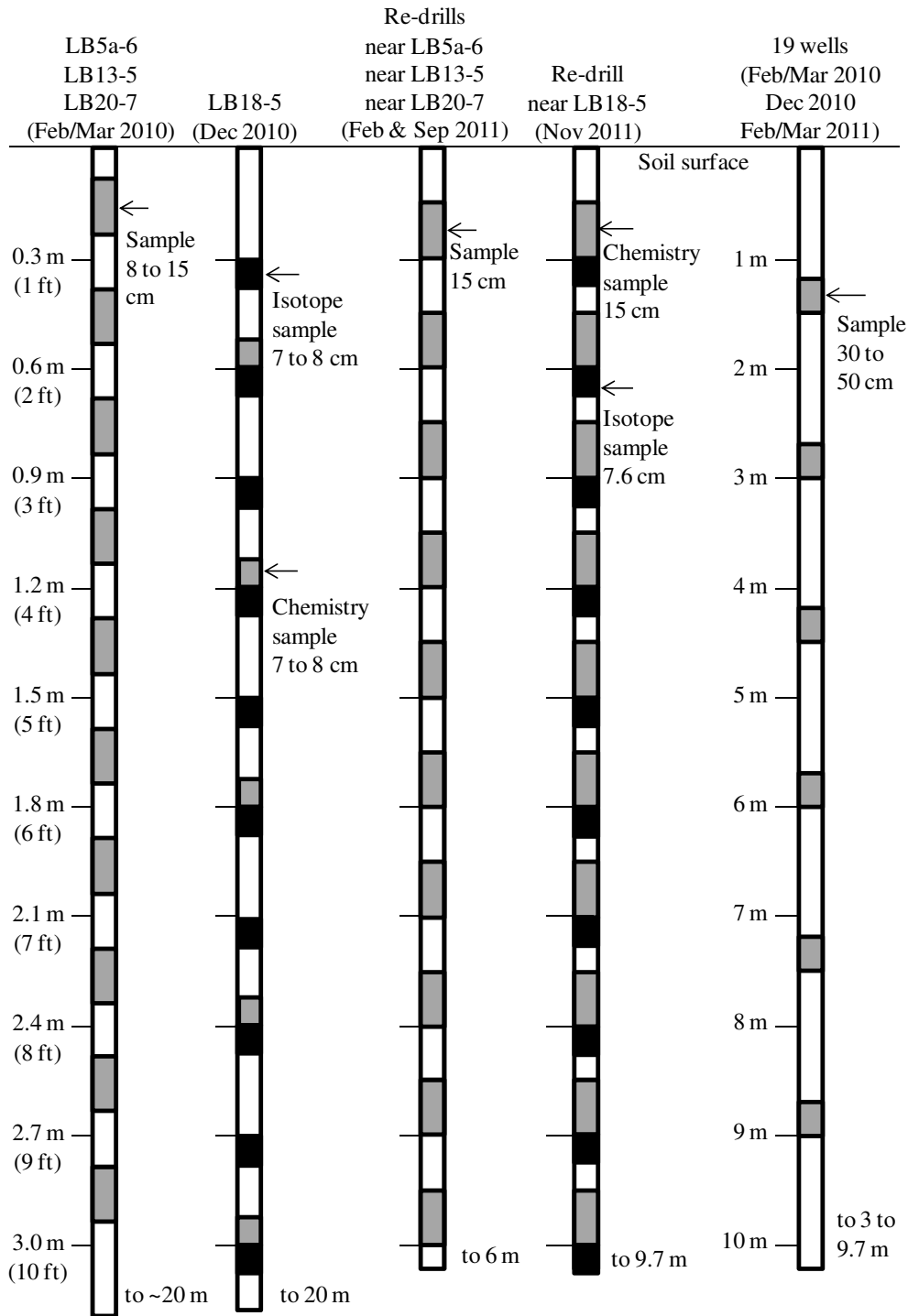


Figure 3.4. Soil sampling profiles for various boreholes in 2010 and 2011. Soil cores were collected for isotope (black bars) and chemical (grey bars) analyses. Cores collected for chemical analyses were also used for analysis of physical parameters. Cores from Feb./Mar. 2012 (grey bars) were split and analyzed for isotopes, chemistry and physical parameters. Cores from Feb./Mar./Sept. 2011 were only analyzed for chemical parameters.

Table 3.1. Boreholes soil sampled at Fields A, B, C, and D in 2010 and 2011.

Field	Well name	Well type	Depth (mbgs)	Sampling date	Description
A	LB5a-1	Water table	3.0	Feb 2010	Every 1.5 m ^x
A	LB5a-6	Piezometer	20.0	Feb 2010 & Feb 2011 ^z	Every foot plus isotopes ^y
A	LB5b-1	Water table	4.0	Feb 2011	Every 1.5 m ^x
A	LB5c-2	Piezometer	10.0	Mar 2011	Every 1.5 m ^x
A	LB5d-1	Water table	4.5	Mar 2011	Every 1.5 m ^x
A	LB5e-2	Piezometer	9.0	Feb 2011	Every 1.5 m ^x
A	LB5f-2	Piezometer	9.0	Feb 2011	Every 1.5 m ^x
B	LB13-5	Piezometer	20.1	Feb 2010 & Feb 2011 ^z	Every foot plus isotopes ^y
B	LB13b-1	Water table	3.0	Mar 2011	Every 1.5 m ^x
B	LB13c-2	Piezometer	9.7	Mar 2011	Every 1.5 m ^x
B	LB13d-2	Piezometer	9.5	Mar 2011	Every 1.5 m ^x
B	LB13e-1	Water table	3.0	Mar 2011	Every 1.5 m ^x
B	LB18-5	Piezometer	20.0	Dec 2010 & Nov 2011 ^z	Every other foot plus isotopes every foot ^y
C	LB20-7	Piezometer	20.7	Mar 2010 & Sept 2011 ^z	Every foot plus isotopes ^y
C	LB20-3	Water table	6.0	Feb 2010	Every 1.5 m ^x
C	LB20a-1	Water table	6.0	Feb/Mar 2010	Every 1.5 m ^x
C	LB20b-2	Piezometer	9.7	Mar 2011	Every 1.5 m ^x
C	LB20c-1	Water table	4.6	Mar 2011	Every 1.5 m ^x
C	LB20d-1	Water table	4.4	Mar 2011	Every 1.5 m ^x
C	LB20e-2	Piezometer	9.7	Mar 2011	Every 1.5 m ^x
D	LB21a-2	Piezometer	9.5	Mar 2011	Every 1.5 m ^x
D	LB21b-1	Water table	4.8	Mar 2011	Every 1.5 m ^x

^z The second date is for the re-drill borehole near the original well.

^y Within each incremental foot layer, the top 7 to 8 cm was sampled for physical and chemical analysis (except for LB18-5, which was every other foot) and the bottom 7 to 8 cm was sampled for isotope analysis.

^x The bottom 30 to 50 cm sampled from every incremental 1.5-m layer.

All soil chemical analysis was carried out by ARD for the following parameters (Appendix 4):

- 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)

Shelby tubes (approximately 7 cm diameter) were used to collect undisturbed soil core samples in February 2011 from two boreholes (LB5c-1 and LB5e-1) at 1.0- to 1.5-m and 4.0- to 4.5-m depths. These samples were used for hydraulic conductivity testing, which was performed by EBA Engineering Consultants Ltd.

In-field Soil Samples

Each field was soil sampled to a depth of about 3 m. Either eight or nine soil cores were collected from each field (Figures 3.1 to 3.3) using a truck-mounted hydraulic soil sampling unit with a 10.2-cm diameter auger. Soil samples were collected from the irrigated area within the fields and the rain fed corners were avoided. At each sampling point, soil samples were collected from 0- to 15-cm, 15- to 30-cm, and every 30-cm increment layer thereafter to a maximum depth of 3 m. Field A was sampled on November 9, 2011, Field B was sampled on November 14, 2011, Field C was sampled on September 29, 2011, and Field D was sampled on September 26, 2011. A total of 374 soil samples were collected. Soil samples were air-dried and ground to pass through a 2 mm sieve.

The dried soil samples were stored and have yet to be analyzed. The samples will be analyzed for extractable NO_3^- -N and NH_4^+ -N (2 M KCl extraction method), STP (modified Kelowna extraction method), total nitrogen (TN) (dry combustion method), and total phosphorus (TP) (acid digestion/autoclave method) (Appendix 5). Electrical conductance, pH, anions and cations will be measured as described above. Organic matter content will also be determined for the top three soil layers (0 to 15 cm, 15 to 30 cm, and 30 to 60 cm) using the loss-on-ignition method.

3.2.5 Point Velocity Probe Instrumentation

One point velocity probe (PVP) stand, with two PVP units, was installed next to Nest LB18 in August 2011. Details about PVP installation are reported in Subsection 2.2.4. Point Velocity Probe data are interpreted by the Universities of Kansas and Saskatoon and are not discussed in the current report.

3.2.6 Well Elevation Surveying

Groundwater wells at Fields A, B, C, and D were surveyed for geodetic elevations in October 2010 and November 2011 by Brown Okamura and Associates Ltd. of Lethbridge, Alberta. The survey was conducted using a survey grade global positioning system unit. Vertical elevations were established relative to mean sea level.

3.2.7 Well Development

Well development was initiated shortly after the wells were installed and prior to the collection of the first water sample from a well. Well development consisted of removing water from the wells using a polyethylene bailer (1 L) and a Waterra 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 at Fields C and D, in the sandier portions of the study area, until water turbidity was visibly reduced.

3.2.8 Groundwater Monitoring

Groundwater Elevation

Groundwater elevations were determined using manual, pressure transducer, and well survey measurements, and the approach is described in Subsection 2.2.7. Groundwater depth measurements were conducted prior to each purging and sampling event during 2010 and 2011, and additional measurements were made on a monthly basis in 2011 when 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 (Levellogger 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, LB5a-4, LB5a-5, and LB5a-6 (Field A); LB13-1, LB13-2, LB13-3, LB13-4, and LB13-5 (Field B); and LB20-5, LB20-6, LB2-7, and LB21-2 (Field C and D). Some pressure transducers were instrumented in the second half of 2010 with all transducers in place by the spring of 2011. All pressure transducers were changed to log every 15-min 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 pressure transducer 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 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. Contours at Field B were prepared using triangulation as fewer wells and data were available.

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 once to twice a month 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 patterns 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. 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. One, 250-mL glass bottle was filled with as little headspace as possible for total organic carbon analysis in August 2011. Samples were placed in coolers with ice packs immediately after collection and 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, NO_3^- -N, NO_2^- -N, ammonia nitrogen (NH_3 -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^- , HCO_3^- , and CO_3^{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 (HNO_3), 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 (SIL) for deuterium (^2H) and oxygen-18 (^{18}O). Isotopic data is 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.

3.2.9 Manure Sampling and Analysis

Solid beef manure samples were collected in 2010 from stock piles at two of the field sites in the Battersea area. Samples were collected October 1, 2010 from a storage pile located in the

northeast corner of Field D. At six points around the pile, three sub-samples were collected at each sampling point from different depths and mixed into composite samples. On October 12, 2010, samples were collected from two stock piles at two locations within Field B. Due to a difference in size, one sample was collected at the smaller pile and five samples were collected at the larger pile in the same manner as described above. Manure at this location had been spread and incorporated on the west half of the field previous to sampling; whereas, the piles were located on the east side of the field. Samples were placed in plastic bags and stored in a freezer prior to chemical analysis (Appendix 9) in 2011 by ALS Group Environmental Laboratory in Saskatoon, Saskatchewan.

On September 21, 2011, manure samples were collected from three solid beef manure piles. One pile was in the northeast corner of Field D, a second pile was in the northwest corner of Field C, and a third pile was along the south edge of Field C. Each pile was sampled as described above with approximately six samples per pile. The samples were stored in a freezer for analysis in 2012.

3.2.10 Irrigation Water Application

The Alberta Irrigation Management Model (AIMM) was used as a tool to predict soil moisture content at the four field sites in 2011, and from these predictions, determine the potential risk of nutrient leaching during the growing season. Model requirements included crop type, seeding date, initial soil moisture, irrigation water applied, and weather data (ARD 2010). Weather data were obtained from the Irrigation Management Climate Information Network (ARD 2010).

Soil moisture samples were collected on July 5 and 8, 2011. Five soil cores were collected at each field site, and each core was sampled in 25-cm increments to a depth of 1 m using a hydraulic drilling truck and 5-cm diameter core tube. Soil texture, moisture content, and bulk density were determined by ARD (Appendix 5). Soil field capacity and permanent wilting point values were estimated based on soil texture using the method by Saxton *et al.* (1986).

The AIMM simulation was initiated on July 5, 2011 for Fields A and B and on July 8, 2011 for Fields C and D. All precipitation and irrigation events were entered into the model simulation after these dates for the duration of the growing season (i.e., until October 31, 2011).

3.2.11 Statistical Analyses

Descriptive statistics were carried out using SYSTAT 13 (Version 13.00.05, SYSTAT Systems, 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 measurable detection limits for each parameter are listed in Appendix 7.

3.3 Results and Discussion

3.3.1 Weather

Total annual precipitation received in 2009, 2010, and 2011 in the Battersea area 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. Further details are in Subsection 2.3.1.

3.3.2 Stratigraphy

Field A

The stratigraphy at Field A is predominantly clay till. At LB5a-6, in the northeast corner of Field A, clay till was encountered from 1 to 20.0 mbgs, with the latter being the maximum depth investigated (Appendix 3). A layer of silty clay loam of lacustrine origin was in the northeast corner of the field (LB5a) and along the southern border of the field (LB5d) to a depth of 2 m. The till had a sand content ranging from 24 to 54% with an average of 44% based on samples collected in LB5a-6. Silt content ranged from 20 to 40% with an average of 26%. Clay content ranged from 24 to 47% with an average of 30%. Laboratory hydraulic conductivity measured on Shelby tube samples from LB5c-1 and LB5e-1 was $3.39 \times 10^{-10} \text{ m s}^{-1}$ at a depth of 4.5 to 5.0 m and $9.93 \times 10^{-11} \text{ m s}^{-1}$ at a depth of 4.5 to 4.9 m, respectively.

Field B

The soil at LB13-5, which is in the southeast corner of Field B, consisted of sand or loamy sand to a depth of 4.2 m, overlying interbedded lacustrine silty clay, silty clay loam, and sandy clay loam to a depth of 18.7 m, followed by clay till to the maximum depth of investigation (20.1 m). Particle size analysis of soil cores from LB13-5 also indicated that soils were predominately sand in the upper 3 m (>92% sand), silty clay loam and silty clay from approximately 4.5 to 15 m, and clay and clay loam from approximately 15 to 18 m. The soil at LB18-5 on the western boundary of the field consisted of 4.5 m of sandy loam overlying lacustrine sandy to silty clay loam to a depth of 8.3 m, overlying clay till to the maximum depth of investigation (20 m). The clay till encountered in both boreholes was unoxidized. The stratigraphy at this site suggests a sloping lacustrine-till contact, which slopes from 858.8 metres above sea level (masl) at LB18-5 (west) to 847.85 masl at LB13-5 (east).

Fields C and D

The stratigraphy at nests LB20 and LB21 was previously described (Rodvang *et al.* 2002), and similar stratigraphy was encountered during well installation in 2010 and 2011. The stratigraphy at LB20 in the southeast corner of Field D consisted of fine-grained sand or sandy loam to a depth of 4.6 m, overlying sandy clay loam and clay to 18.3 mbgs. Particle size analysis from LB20-7 indicated that soils were predominantly sand (greater than 90%) in the upper 3 m, transitioning to loam, silty clay loam, and clay loam as depth increased. The stratigraphy at LB21 in the northeast corner of Field C consisted of fine-grained sand from

ground surface to a depth of 21.3 mbgs, overlaying sandy loam to 24.4 mbgs and sandy clay to 27.4 mbgs. Sand was near the ground surface, extending to depths of 2 mbgs at LB20 and to depths of at least 10 mbgs at LB21, as identified in a 10-m borehole drilled adjacent to LB21b-2.

3.3.3 Well Borehole and In-field Soil Chemistry

Results of the analyses from borehole soil cores collected during the installation of the deeper wells were used to interpret some of the groundwater results and are discussed in subsequent subsections. Soil chemistry analysis was not completed for the in-field soil samples collected in 2011.

3.3.4 Groundwater Elevation

Field A

Groundwater flow direction at the water table was from the west to east (Figure 3.5). Horizontal hydraulic gradient at the water table was estimated to be 0.01 m m^{-1} .

The average depth to groundwater at Field A was 1.30 mbgs (2010 to 2011) and the depth to the water table ranged from 0.29 (LB5a-1 on June 6, 2011) to 3.48 mbgs (LB5f-1 on August 23, 2011). Groundwater elevations for individual wells are in Appendix 8.

Groundwater levels responded differently at depth to purging and sampling events. A dynamic groundwater response was observed at LB5a-1, a water table well, likely in response to precipitation and irrigation events as well as evapotranspiration (Figure 3.6). In contrast to LB5a-1, a long recovery time was observed after purging and sampling events at LB5a-4, LB5a-5, and LB5a-6, where water levels returned to static levels between sampling events. Groundwater levels in the deeper piezometers (e.g., LB5a-6) appeared less responsive to precipitation and irrigation events (Appendix 8).

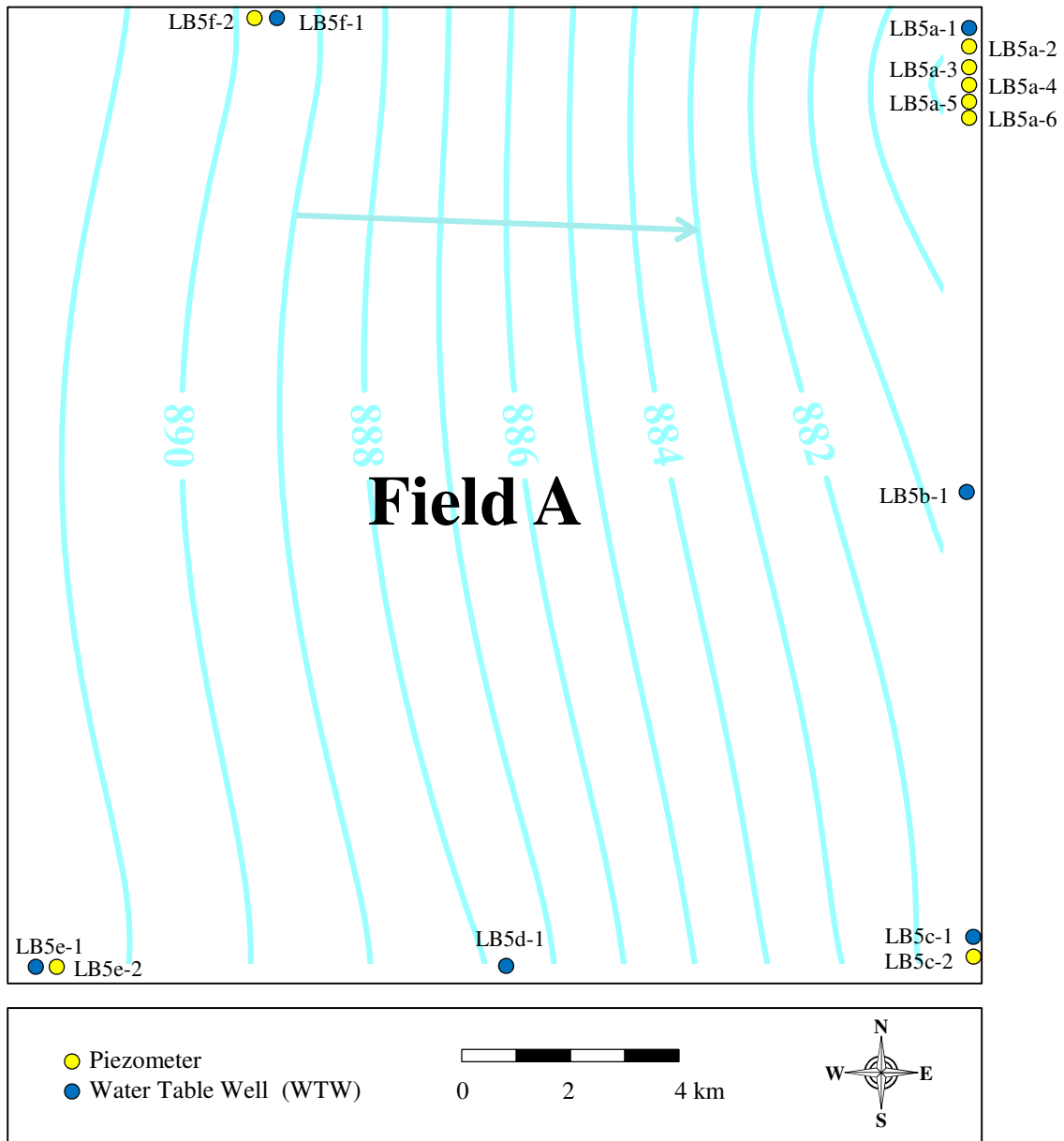


Figure 3.5. Shallow groundwater elevation at Field A in October 2011 (1-m contour interval; numbers represent metres above sea level; arrow indicates inferred groundwater flow direction).

Estimates of vertical groundwater gradients were calculated for the nested wells at Field A. Vertical gradients generally indicated recharging conditions at the field (i.e., gradients directed downward) except at LB5c in the southeast corner of the field where gradients indicated discharging groundwater conditions (i.e., upward flow) in August and October (Appendix 11).

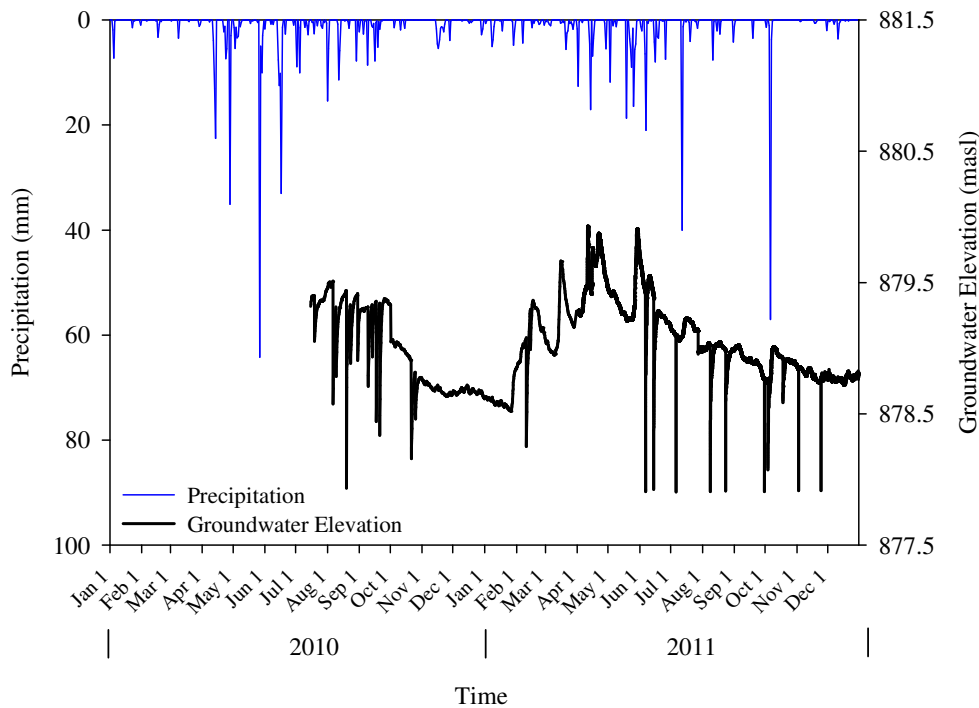


Figure 3.6. Groundwater elevation in water table well LB5a-1 and precipitation in the Battersea area from 2010 to 2011. The sharp descents in groundwater elevation occurred when the water table dropped after well purging and sampling.

Field B

Groundwater flow direction at the water table was from south to north for Field B (Figure 3.7). However, contours will need to be calculated again in subsequent years as some of the wells were dry in 2011. New wells were installed in late 2011 to allow for the determination of groundwater flow direction in subsequent years of the study.

The average depth to the water table at Field B was 2.23 mbgs (2010 to 2011). The depth to the water table ranged from 0.62 (LB13b-1 on June 10, 2011) to 3.76 mbgs (LB13d-1 on August 23, 2011).

Groundwater levels responded differently in the lacustrine and clay deposits as well as to purging and sampling events. Well LB13-5, a deep piezometer completed with a screen in the clay till, showed slow recovery after purging and sampling events with the water level returning to static conditions only shortly before subsequent purging events (Figure 3.8). Groundwater elevations measured in wells in the lacustrine deposits changed in tandem (Figure 3.9), suggesting that the upper lacustrine deposits are acting as a single hydrogeological unit. However, at LB13-2 (screened from 9.7 to 11.3 mbgs), groundwater elevations recovered somewhat slowly between purging and sampling events compared to the shallower wells

installed at LB13, indicating that the well is completed within a lower permeability zone of the lacustrine deposits.

Estimates of vertical groundwater gradients were calculated for the nested wells at Field B. Vertical gradients generally indicated recharging conditions (i.e., gradients directed downward) except for LB18-1x and LB18-4 during the August and October 2011 monitoring event when the gradients indicated discharging groundwater conditions (i.e., upward flow) (Appendix 11).

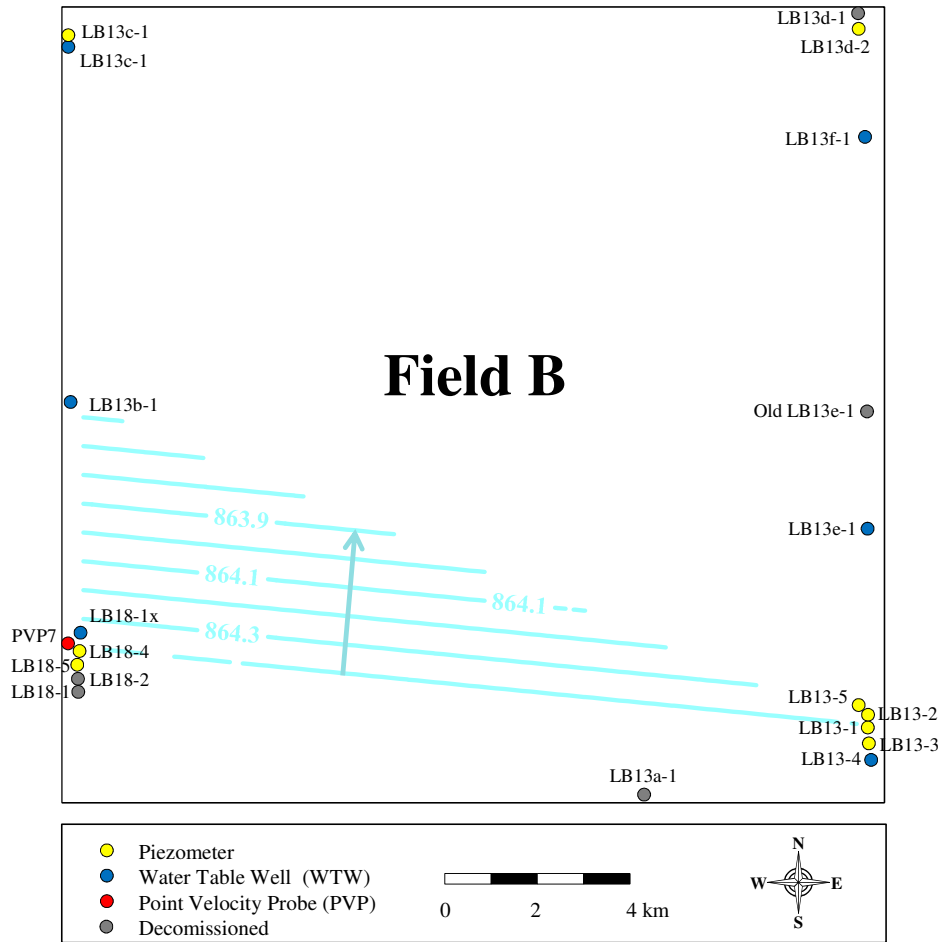


Figure 3.7. Shallow groundwater elevation at Field B in October 2011 (0.1-m contour interval; numbers represent metres above sea level; arrow indicates inferred groundwater flow direction).

Fields C and D

Groundwater flow direction at the water table at Fields C and D is from the northeast to southwest (Figure 3.10). Flow direction is influenced by a topographic high to the east of the fields. The horizontal hydraulic gradient at the water table is estimated to be 0.005 m m^{-1} .

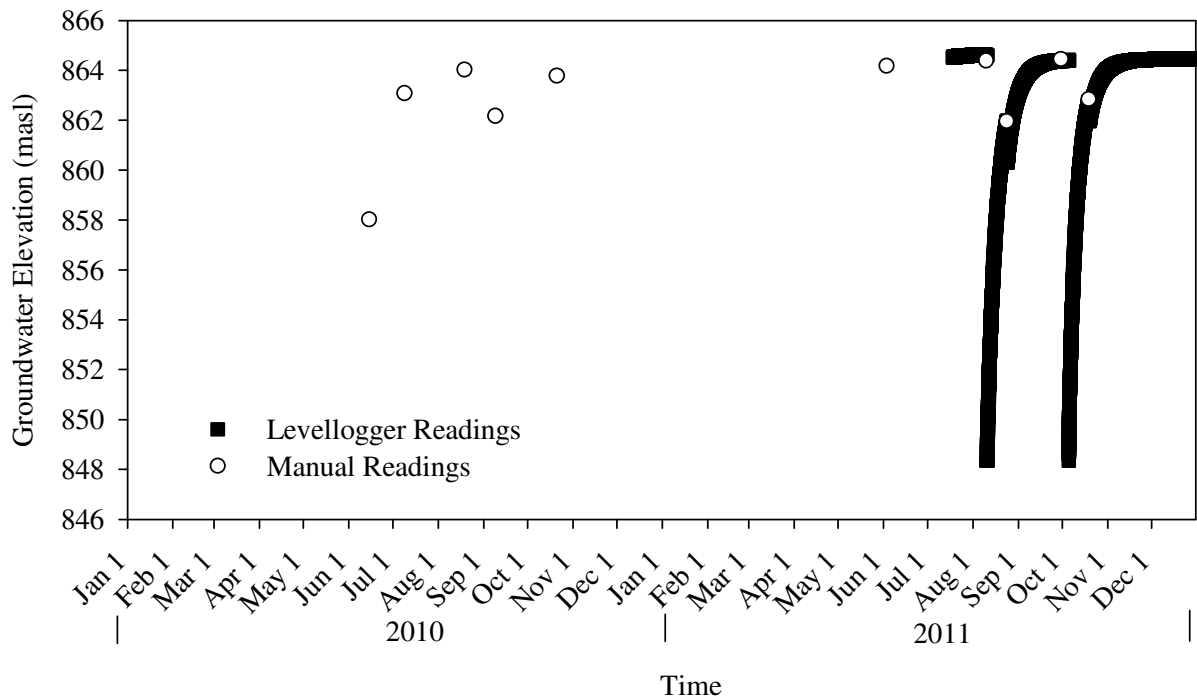


Figure 3.8. Groundwater elevation in the deep piezometer LB13-5, which was screened in clay till.

The depth to water table at Fields C and D ranged from 0.39 mbgs at LB20a-1 on March 31, 2010 to 4.36 mbgs at LB20-3 on March 31, 2010. The mean water table for all monitoring events at all wells was 2.23 mbgs (Appendix 8).

Water levels recorded in piezometers LB20-5 and LB20-6 showed nearly identical fluctuations (Figure 3.11), suggesting that these wells were completed in a single hydrostratigraphic unit. Water levels in LB20-7 also showed a similar response, but the response was muted, suggesting that this well is deeper and more isolated from changes in groundwater levels occurring above.

Fluctuations in water levels in the shallow water table wells and deeper piezometers were generally influenced by precipitation events. This was most evident in wells with pressure transducers. Groundwater levels from July 9 to 26, 2011 increased shortly after 47 mm of precipitation fell on the study area, including a single precipitation event of 40 mm that occurred on July 12 (Figure 3.12). Groundwater levels also responded to a rainfall event of 57 mm on October 6, 2011, although the change in level was smaller than in July.

Estimates of vertical groundwater flow were calculated for the nested wells at Fields C and D. Vertical gradients generally indicated recharging conditions (i.e., gradients directed downward) (Appendix 11).

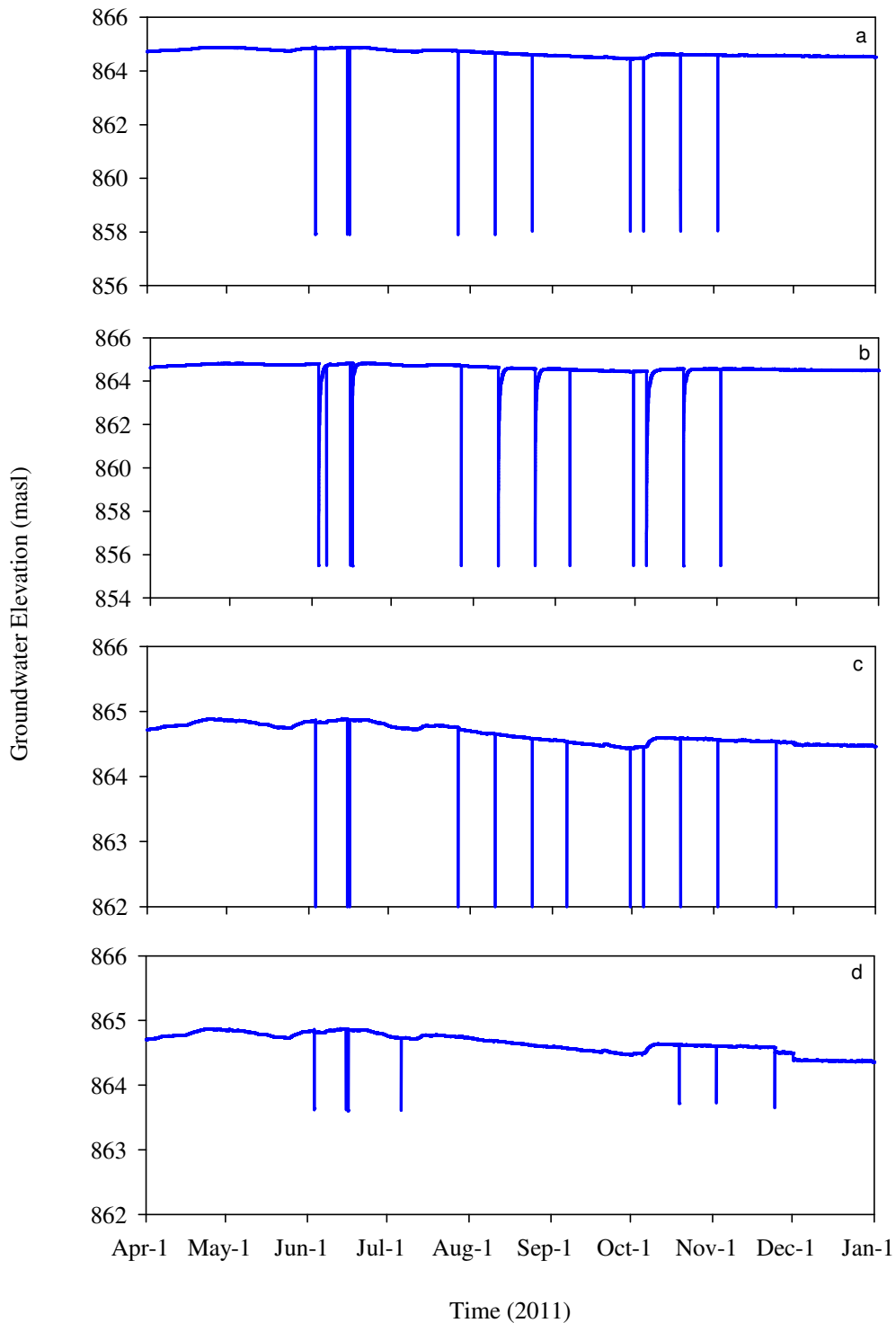


Figure 3.9. Groundwater elevations at nest LB13 for Wells (a) LB13-1 (858.06 masl), (b) LB13-2 (855.44 masl), (c) LB13-3 (861.80 masl), and (d) LB13-4 (863.77 masl). Well LB13-4 is a water table well and the others are piezometers. Bottom-of-screen elevations are in parentheses.

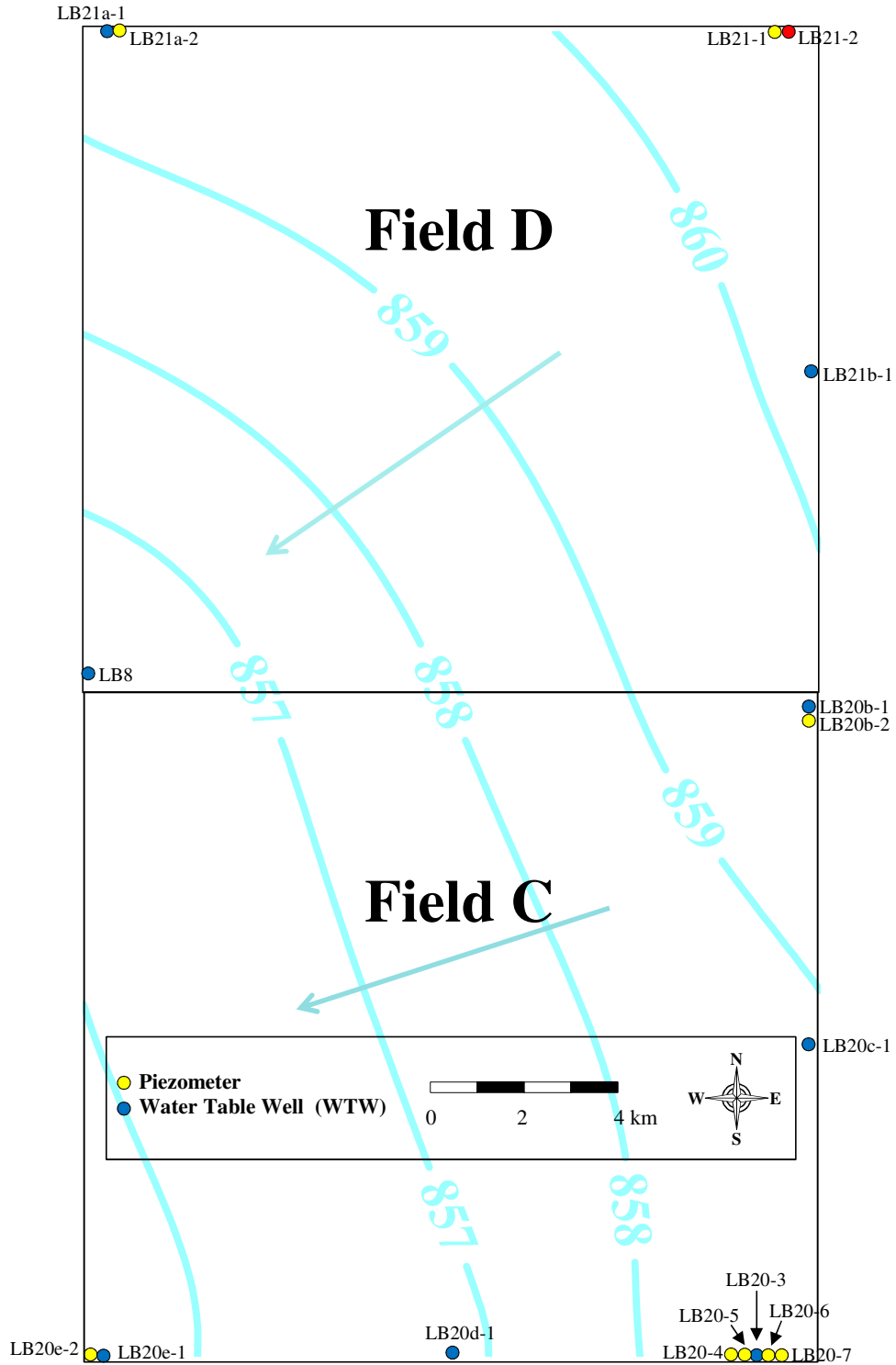


Figure 3.10. Shallow groundwater elevation at Fields C and D in October 2011 (1-m contour interval; numbers represent metres above sea level; arrows indicate inferred groundwater flow direction).

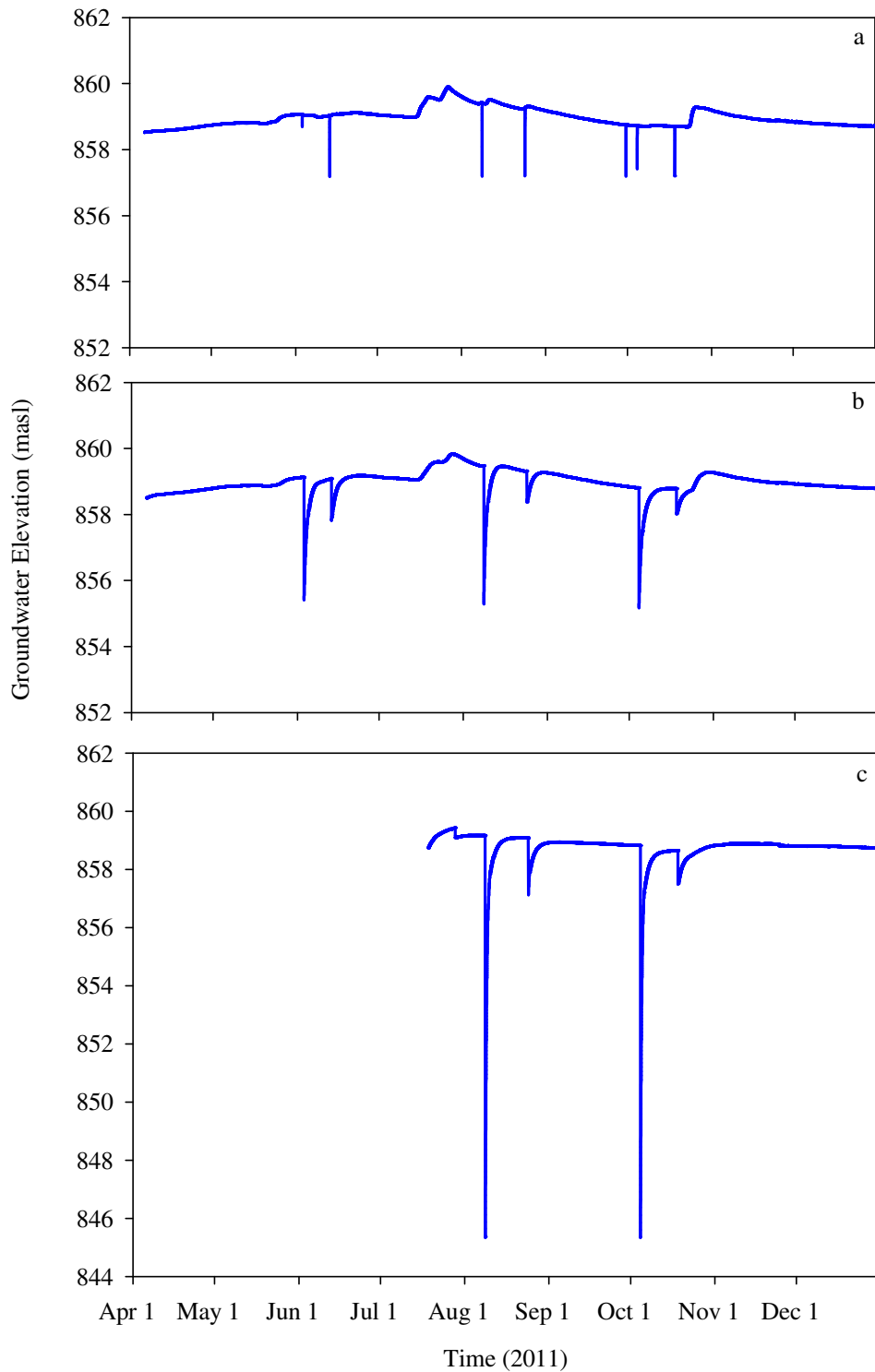


Figure 3.11. Groundwater elevation with time in piezometers at nest LB20 for Wells (a) LB20-5 (857.05masl), (b) LB20-6 (855.10 masl), and (c) LB20-7 (842.51 masl). Bottom-of-screen elevations are in parentheses.

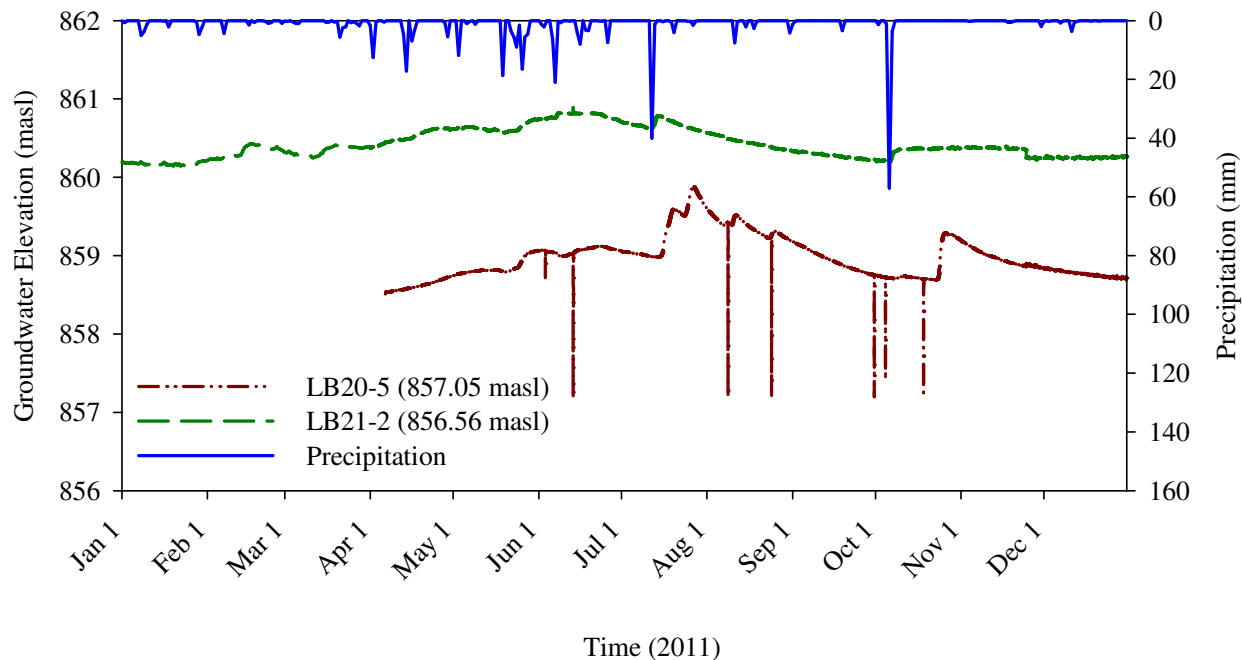


Figure 3.12. Groundwater elevation in piezometer LB20-5 and water table well LB21-2 and daily precipitation in 2011. Bottom-of-screen elevations are shown in parentheses in the legend.

3.3.5 Groundwater Chemistry

Groundwater chemical summary statistics are presented in Appendix 10. For purposes of this report, concentrations of NO_3^- -N and Cl^- have been used as indicators of impact from agricultural operations and are discussed in detail. Refer to Subsection 1.1 for discussion of NO_3^- -N and Cl^- as manure indicators.

Field A

Wells at Field A were instrumented in 2010 and 2011, thus, limited chemistry data are available for the new wells installed in 2011. Therefore, the following discussion will focus on results for the wells installed at LB5a, which have 2 yr of data, with limited discussion for other nests in the field.

Chloride concentrations in water table wells around Field A were elevated, while NO_3^- -N concentrations were generally at or close to the minimum measurable detection limit (MMDL; Table 3.2). The mean Cl^- concentration in the water table well in the northeast corner of Field A (LB5a-1) was 28 mg L^{-1} . Chloride concentrations in this well increased in response to increasing groundwater elevation (Figure 3.13). Chloride concentrations in the other water table wells were higher than those in LB5a-1, with the exception of LB5d-1, which had concentrations below the

MMDL. A maximum NO_3^- -N concentration of 1.64 mg L^{-1} was measured in LB5b-1 (Table 3.2). These initial results suggest that Cl^- and NO_3^- -N concentrations did not increase in the water table in the presumed down-gradient direction across the field.

Table 3.2. Concentrations of chloride (Cl^-), nitrate nitrogen (NO_3^- -N), and ammonia nitrogen (NH_3 -N) for individual wells at Field A from 2010 to 2011.

Well ^z	Bottom of well screen (mbgs)	Cl^-			NO_3^- -N			NH_3 -N		
		Min. ^y	Max.	Mean ^x	Min. ^w	Max.	Mean ^x	Min. ^w	Max.	Mean ^x
LB5a-1	3.0	16	74	28	0.05	0.22	0.07	0.05	0.05	0.05
LB5a-2	2.5	28	92	47	0.05	0.05	0.05	0.05	0.15	0.06
LB5a-3	1.0	21	40	29	0.05	0.05	0.05	0.05	0.05	0.05
LB5a-4	7.0	78	98	83	4.25	13.6	9.32	0.05	1.95	1.04
LB5a-5	10.0	170	209	183	115	198	173	0.16	3.96	2.10
LB5a-6	20.0	35	181	79	0.05	0.17	0.07	9.86	10.8	10.4
LB5b-1	4.0	78	89	83	1.51	1.64	1.58	0.05	0.05	0.05
LB5c-1	4.0	35	121	65	0.05	0.34	0.15	0.05	8.38	5.56
LB5c-2	10.0	35	113	86	0.05	0.50	0.29	0.05	8.54	2.90
LB5d-1	4.5	5	5	5	0.05	0.05	0.05	0.05	0.05	0.05
LB5e-1	4.0	39	110	74	0.05	0.30	0.18	0.05	0.05	0.05
LB5e-2	9.0	14	99	57	0.05	0.12	0.09	0.05	0.05	0.05
LB5f-1	4.5	85	99	91	0.05	0.05	0.05	0.05	0.05	0.05
LB5f-2	9.0	21	25	22	0.05	0.05	0.05	0.05	0.15	0.08

^z LB5a-1, LB5b-1, LB5c-1, LB5d-1, LB5e-1, and LB5f-1 are water table wells, and all others are piezometers. Data for wells at LB5a (1 to 6) are from 2010 and 2011, and data from the other wells are from 2011.

^y MMDL of 10 mg L^{-1} . Half the MMDL shown in table.

^x Standard deviations are reported in Appendix 10.

^w MMDL of 0.1 mg L^{-1} . Half the MMDL shown in table.

Groundwater Cl^- and NO_3^- -N concentrations at nest LB5a tended to increase with depth to 10.0 mbgs, after which concentrations decreased (Figures 3.14 and 3.15). Similar to the groundwater NO_3^- -N concentration, soil NO_3^- -N concentration increased to a maximum at 10 mbgs, after which the concentration decreased (Figure 3.15). The cause of the increase in NO_3^- -N concentrations followed by the decrease below 10 m is not known at this time. Groundwater NO_3^- -N concentrations in piezometers at other nests at the field ranged from the MMDL to a maximum of 0.33 mg L^{-1} (Table 3.2), suggesting that the increase in NO_3^- -N with depth is localized and not widespread at this field site. Age dating of the groundwater will help determine if this increased concentration of NO_3^- -N at a depth to 10 m at LB5a is associated with agricultural impacts or is attributable to geological nitrate in the clay till.

Among the wells at nest LB5a, a seasonal pattern was observed for Cl^- and NO_3^- -N concentrations in water table well LB5a-1 (Figure 3.16). The highest concentrations were observed in the spring (May and June) in 2010 and 2011.

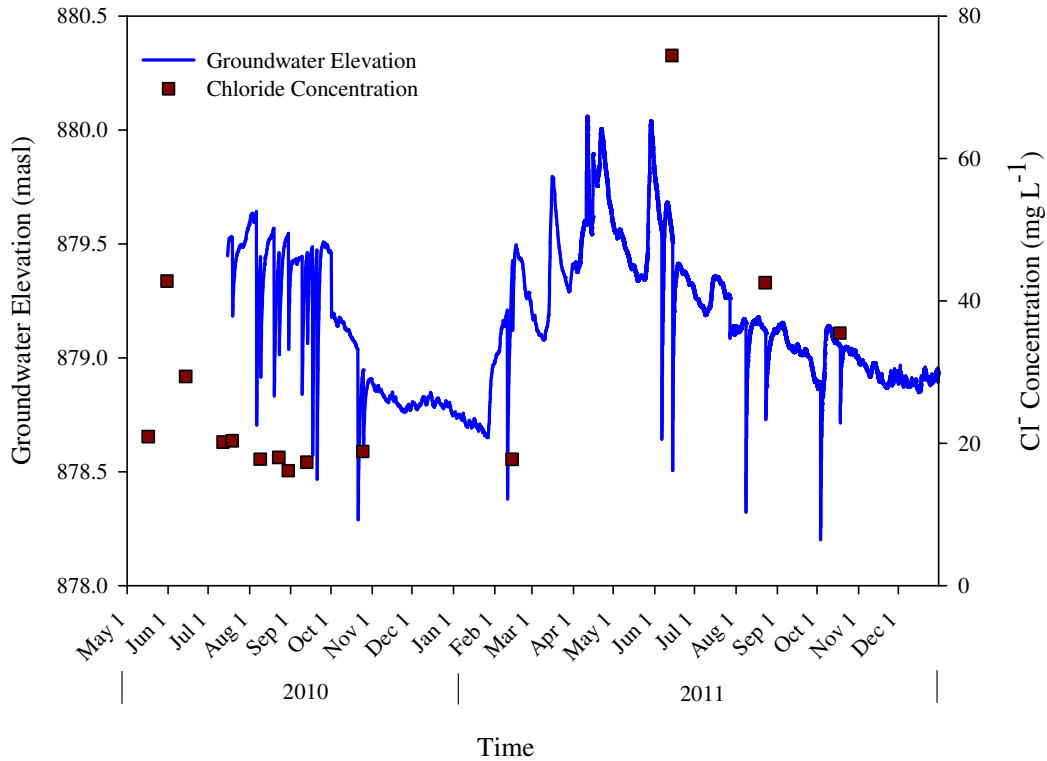


Figure 3.13. Groundwater elevation and chloride (Cl⁻) concentration at water table well LB5a-1 in 2010 and 2011.

Field B

Nitrate-N concentrations at Field B were generally close to or at the MMDL, except at water table wells LB13-4 and LB18-1 and shallow piezometer LB13-3. Nitrate N concentrations in these three wells ranged from 5.4 to 90.45 mg L⁻¹ (Table 3.3). The screens at wells LB13-4 and LB13-3 overlapped, and therefore, samples from these two wells may represent the same groundwater. Seasonal patterns will be assessed in subsequent years when more data are available.

The mean Cl⁻ concentrations at nest LB13, in the southeast corner of Field B, and nest LB18, in the southwest corner, decreased with increasing depth from the ground surface (Figure 3.17). Chloride concentrations ranged from the MMDL to 125 mg L⁻¹ (Table 3.3). The decrease in Cl⁻ concentrations, combined with the lack of NO₃⁻-N in the groundwater samples at depth, may suggest that the transport of manure constituents to depth is not occurring at this location.

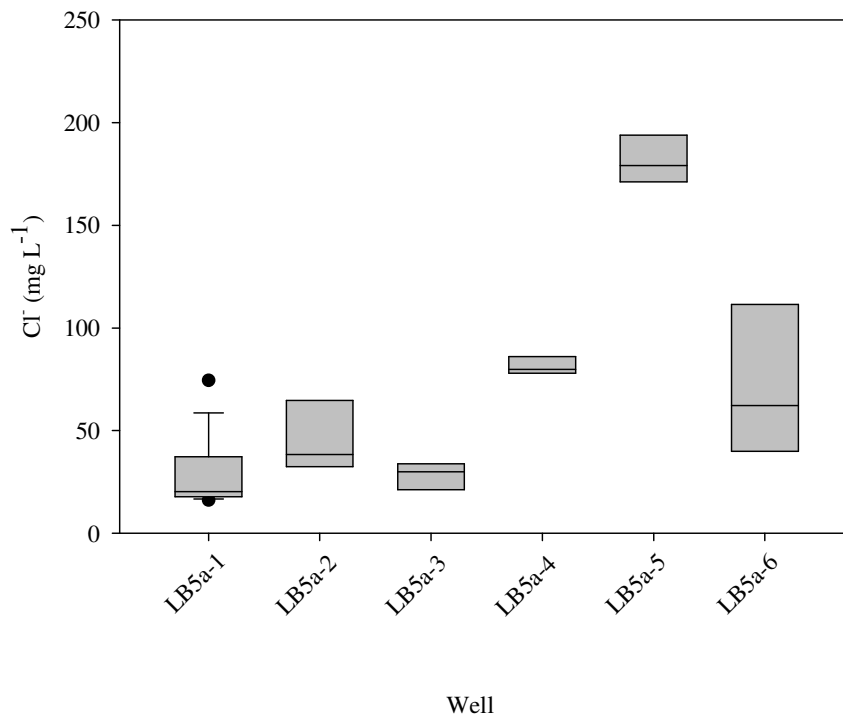


Figure 3.14. Chloride (Cl⁻) concentrations from 2010 to 2011 in a water table well (LB5a-1) and piezometers instrumented at Nest LB5a displayed from shallowest (left) to deepest (right) piezometers (LB5a-2 to LB5a-6). Boxplots stretch from the 25th percentile to the 75th percentile with the horizontal line in the middle of the box representing the median. Whiskers (error bars) above and below the box represent the 10th and 90th percentiles, while dots represent outlying data points. Whiskers and outliers were not computed or presented for wells with less than the required nine data points.

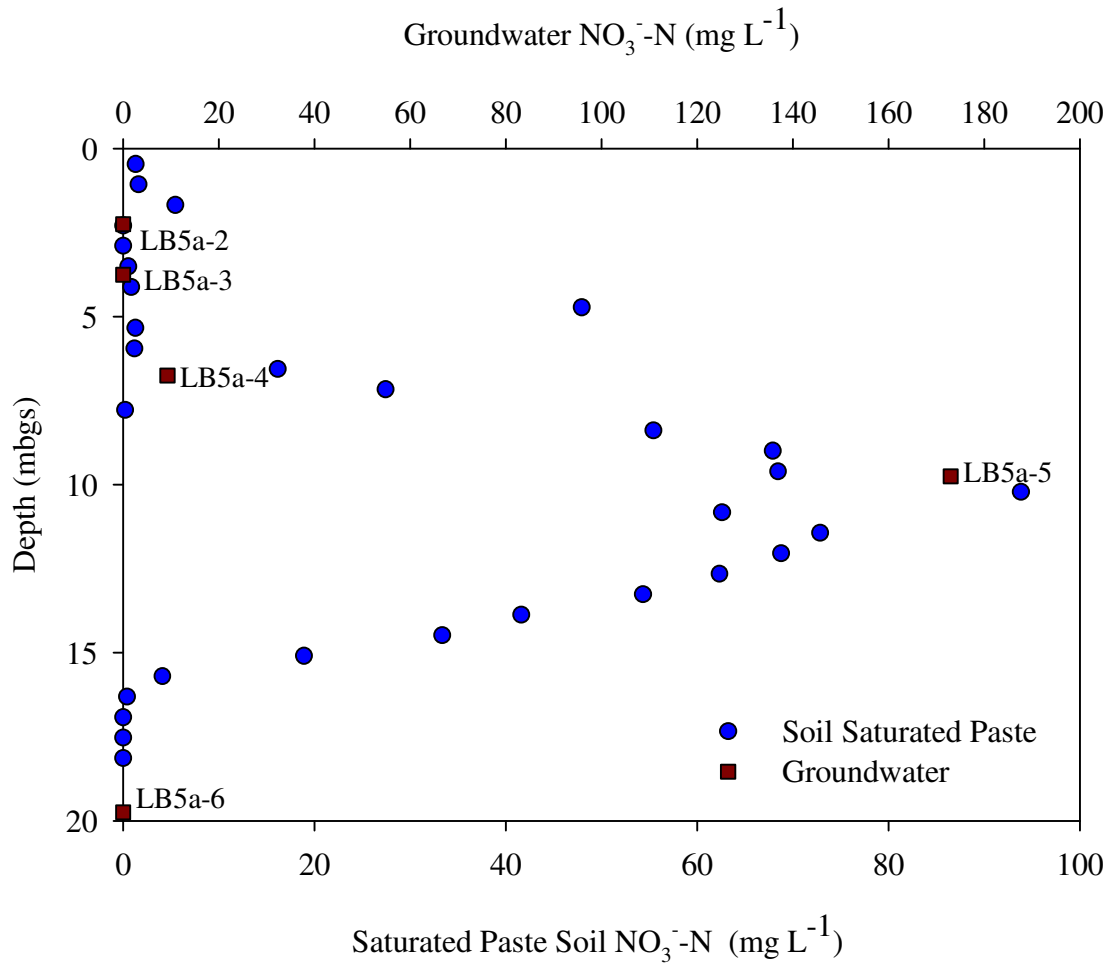


Figure 3.15. Groundwater (five piezometers) and soil nitrate nitrogen (NO₃⁻-N) concentrations at nest LB5a. Groundwater NO₃⁻-N concentrations are mean values, and soil NO₃⁻-N concentrations are from February 2010 measurements.

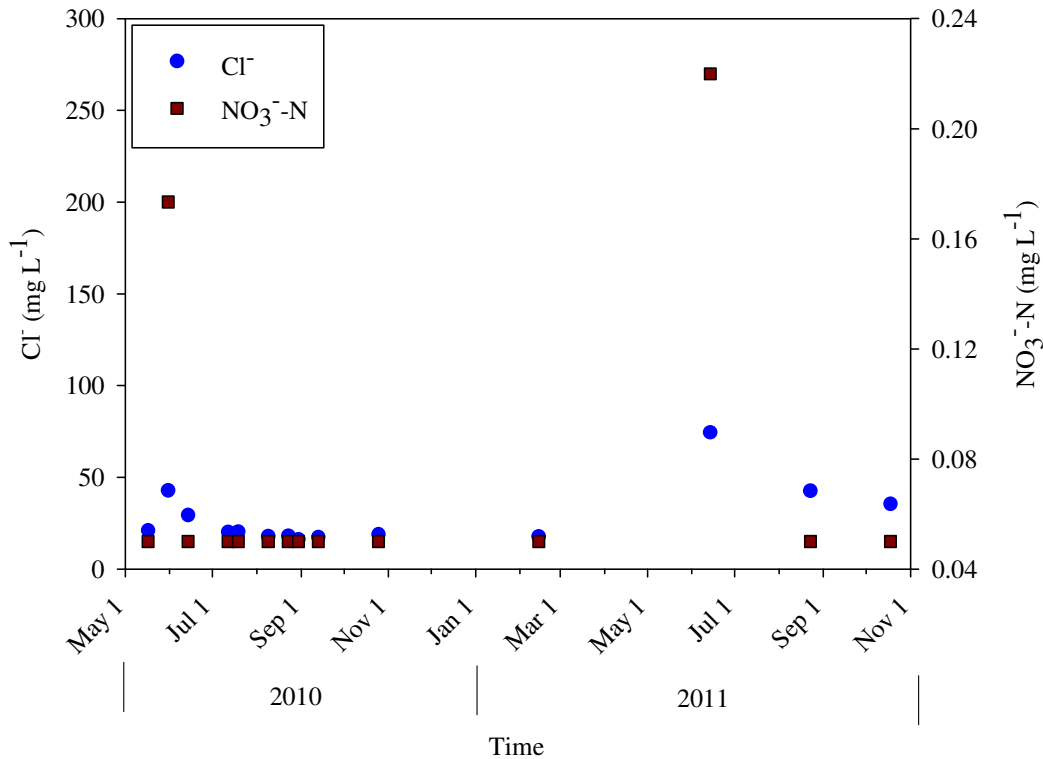


Figure 3.16. Chloride (Cl⁻) and nitrate nitrogen (NO₃⁻-N) concentrations in water table well LB5a-1 from 2010 to 2011.

Table 3.3. Concentrations of chloride (Cl⁻), nitrate nitrogen (NO₃⁻-N), and ammonia nitrogen (NH₃-N) for individual wells at Field B in 2010 and 2011.

Well ^z	Bottom of well screen (mbgs)	Cl ⁻			NO ₃ ⁻ -N			NH ₃ -N		
		Min. ^y	Max.	Mean ^x	Min. ^w	Max.	Mean ^x	Min. ^w	Max.	Mean ^x
LB13-4	2.66	5	125	89	5.41	57	212	0.05	0.33	0.06
LB13-3	4.58	60	82	70	17.7	69	41	0.19	1.06	0.45
LB13-1	8.40	38	53	44	0.05	0.05	0.05	0.05	0.14	0.11
LB13-2	11.04	5	5	5	0.05	0.05	0.05	0.33	0.38	0.35
LB13-5	20.1	5	5	5	0.05	0.05	0.05	0.39	0.69	0.56
LB13b-1	3.0	167	174	170	0.05	0.55	0.22	0.25	0.49	0.37
LB13c-2	9.7	35	39	37	0.05	0.05	0.05	0.33	0.36	0.35
LB13d-2	9.5	248	266	259	0.05	0.05	0.05	0.05	0.05	0.05
LB18-1x	3.0	46	64	55	39.6	90	66	0.05	0.05	0.05
LB18-4	10.0	11	50	29	0.05	0.05	0.05	0.19	0.59	0.45
LB18-5	20.0	11	21	17	0.05	1.51	0.42	0.38	0.75	0.64

^z LB13-4, LB13b-1, and LB18-1x are water table wells, and all others are piezometers. Data for wells at LB13 (1 to 5) are from 2010 and 2011, and data from the other wells are from 2011.

^y MMDL of 10 mg L⁻¹. Half the MMDL shown in table.

^x Standard deviations are reported in Appendix 10.

^w MMDL of 0.1 mg L⁻¹. Half the MMDL shown in table.

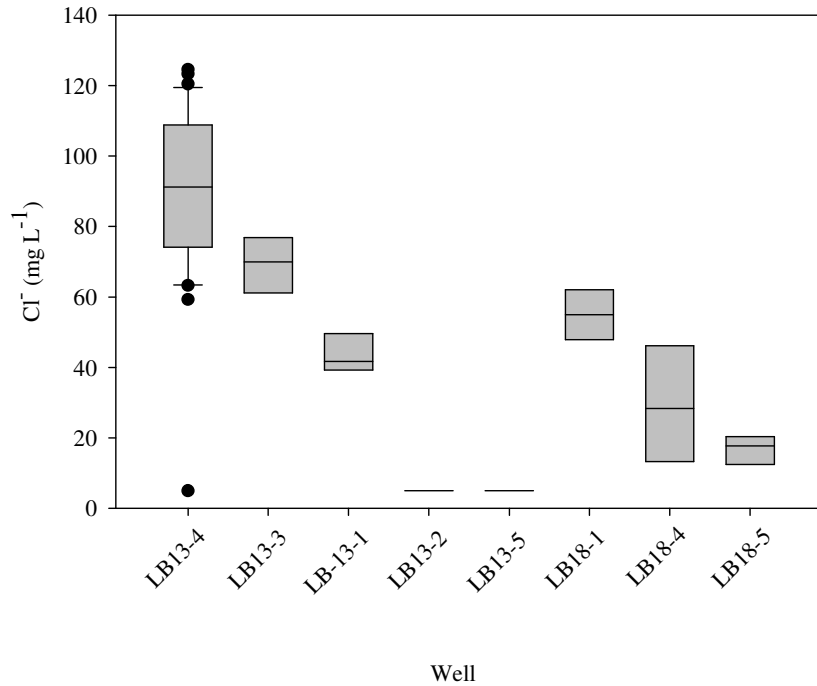


Figure 3.17. Chloride (Cl⁻) concentrations in 2010 and 2011 in water table wells (LB13-4, LB18-1) and piezometers instrumented at Nests LB13 and LB18 at Field B. The piezometers are displayed from shallowest (left) to deepest (right) piezometer (LB13-3 to LB13-5 and LB18-4 to LB18-5). Boxplots stretch from the 25th percentile to the 75th percentile with the horizontal line in the middle of the box representing the median. Whiskers (error bars) above and below the box represent the 10th and 90th percentiles, while dots represent outlying data points. Whiskers and outliers were not computed or presented for wells with less than the required nine data points. Fields C and D

The mean NO₃⁻-N concentration ranged from the MMDL to 74 mg L⁻¹, and the mean Cl⁻ concentration ranged from the MMDL to 147 mg L⁻¹ at Fields C and D (Table 3.4). Generally, NO₃⁻-N and Cl⁻ concentrations were elevated in wells along the western edge of Fields C and D. The elevated concentrations in the nests along the western edge of the fields suggest groundwater impact occurred from manure spreading. Nest LB21, in the northeast corner of Field D, and Nest LB20, in the southeast corner of Field C, had elevated concentrations in the water table wells and shallow piezometers; whereas, NO₃⁻-N and Cl⁻ concentrations were very low or not detected at depths greater than 8 mbgs (Table 3.4, Figures 3.18 and 3.19). Elevated Cl⁻ concentrations were measured in the deeper piezometers at Nests LB21a and LB20e along the western edge of Fields C and D; however, elevated NO₃⁻-N concentration was not detected in the same piezometers. It is not clear if there is localized transport of manure constituents to depth at Fields C and D. Seasonal patterns were not apparent from 2010 to 2011 but will be assessed again in subsequent years when more data are available.

Table 3.4. Concentrations of chloride (Cl⁻), nitrate nitrogen (NO₃⁻-N), and ammonia nitrogen (NH₃-N) for individual wells at Fields C and D in 2010 and 2011.

Well ^z	Bottom of well screen (mbgs)	Cl ⁻			NO ₃ ⁻ -N			NH ₃ -N		
		Min. ^y	Max.	Mean ^x	Min. ^w	Max.	Mean ^x	Min. ^w	Max.	Mean ^x
LB20-3	6.0	30	135	91	0.22	4.15	2.04	0.05	0.21	0.07
LB20-4	3.5	85	85	85	3.32	3.32	3.32	0.11	0.11	0.11
LB20-5	5.5	82	121	98	0.39	3.57	1.86	0.05	0.71	0.22
LB20-6	8.0	5	5	5	0.05	0.05	0.05	0.20	0.24	0.23
LB20-7	20.7	5	5	5	0.05	0.05	0.05	0.24	0.42	0.36
LB20a-1	6.0	29	50	35	0.05	0.56	0.23	0.05	0.27	0.17
LB20b-1	4.5	5	269	146	0.05	115	74	0.05	0.31	0.14
LB20b-2	9.7	5	135	48	0.05	122	401	0.05	0.30	0.20
LB20c-1	4.6	32	71	46	1.49	3.18	2.54	0.05	0.05	0.05
LB20d-1	4.4	50	67	59	0.96	1.73	1.32	0.05	0.05	0.05
LB20e-1	5.0	28	199	99	3.49	44.9	18	0.05	0.10	0.07
LB20e-2	9.7	35	53	43	0.05	0.05	0.05	0.96	1.06	1.01
LB21-1	18.94	5	5	5	0.16	0.37	0.26	0.32	0.67	0.45
LB21-2	5.57	18	33	25	8.65	24.6	19	0.05	0.19	0.07
LB21a-1	4.8	28	99	64	52.3	81.4	68	0.05	0.05	0.05
LB21a-2	9.5	32	35	33	0.05	0.05	0.05	0.31	0.37	0.33
LB21b-1	4.8	14	43	26	36.04	47.12	41.93	0.05	0.05	0.05

^z LB20-3, LB20a-1, LB20b-1, LB20c-1, LB20d-1, LB20e-1, LB21-2, LB21a-1, and LB21b-1 are water table wells, and all others are piezometers. Data for LB21-2 are from 2010 and 2011, and data from the other wells are from 2011.

^y MMDL of 10 mg L⁻¹. Half the MMDL shown in table.

^x Standard deviations are reported in Appendix 10.

^w MMDL of 0.1 mg L⁻¹. Half the MMDL shown in table.

3.3.6 Manure

Water and dry matter content of beef manure was similar between Fields B and D in October 2010 (Table 3.5). Ammonium N content was also similar between the two fields. However, the concentrations of many other parameters were higher in Field B manure compared to Field D manure. For example, total C was two-fold greater, TN was 1.7-fold greater, TP was 2.7-fold greater, and Cl was 2.9-fold greater in the manure at Field B compared to Field D. Manure analysis results reported from three feedlots during an 8-yr period in the Picture Butte area were similar to the manure from Field B (Olson *et al.* 2003, 2009). The reasons why the nutrient content was generally lower in the manure from Field D may include differences in animal diet, storage conditions, amount of bedding used, and the amount of soil material mixed with the manure during removal from the pens.

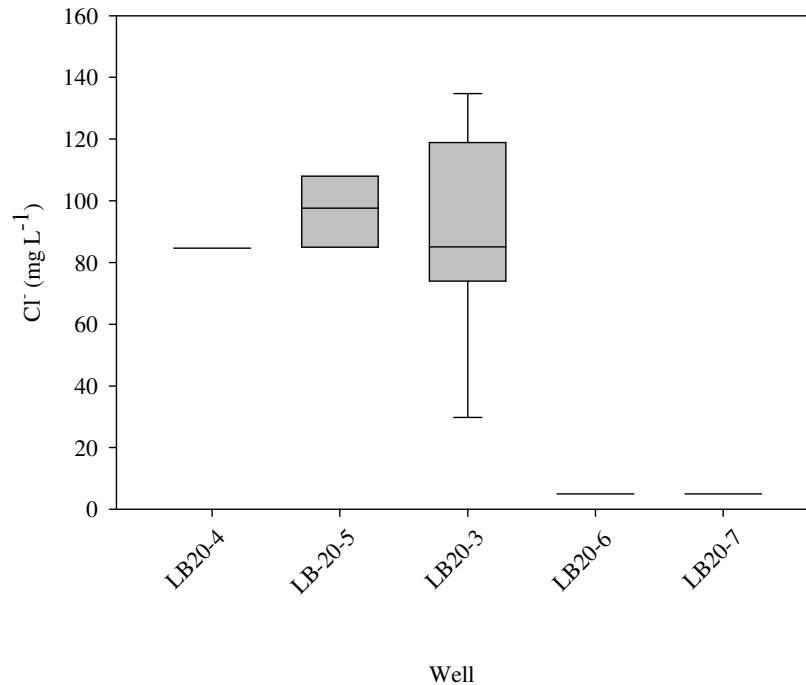


Figure 3.18. Chloride (Cl⁻) concentrations in 2010 and 2011 in the water table well (LB20-3) and piezometers installed at Nest LB20 at Field C, displayed from shallowest (left) to deepest (right). Boxplots stretch from the 25th percentile to the 75th percentile with the horizontal line in the middle of the box representing the median. Whiskers (error bars) above and below the box represent the 10th and 90th percentiles. Whiskers and outliers were not computed or presented for wells with less than the required nine data points.

3.3.7 Irrigation Water Application

Soil moisture content was high at each field when the model was initiated on July 5 (Fields A and B) and July 8 (Fields C and D), 2011. The mean available soil moisture content in the 0- to 100-cm soil layer ranged from 143 to 196 mm among the four fields (Table 3.6). The soils were essentially at field capacity moisture content or at 100% available moisture content in early July.

The AIMM output showed soil moisture generally remained above field capacity from July to mid-August for all field sites and then decreased through the fall (Figures 3.20 to 3.23). Therefore, movement of water downward into the soil profile and the risk of nutrient leaching was likely greatest during July and August. Although available soil moisture decreased from late summer to fall at Fields A, C, and D, predicted available soil moisture at Field B increased with irrigation and precipitation events in August, September, and October 2011. Available soil moisture remained less than field capacity even with the addition of irrigation water and precipitation. Water table elevation increased in response to precipitation and irrigation events in July and October 2011 at Fields B, C, and D (Appendix 8, LB13-4, LB20-3, and LB21-2), and this suggests that the downward movement of water occurred, and potentially nutrient leaching, when available soil moisture was close to or above field capacity.

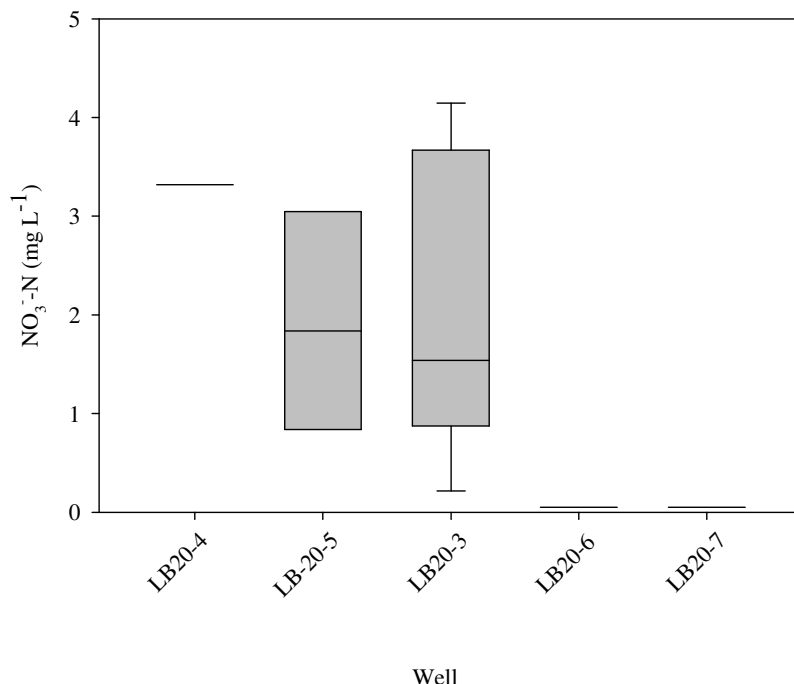


Figure 3.19. Nitrate nitrogen (NO_3^- -N) concentrations in 2010 and 2011 in the water table well (LB20-3) and piezometers installed at Nest LB20 at Field C, displayed from shallowest (left) to deepest (right). Boxplots stretch from the 25th percentile to the 75th percentile with the horizontal line in the middle of the box representing the median. Whiskers (error bars) above and below the box represent the 10th and 90th percentiles. Whiskers and outliers were not computed or presented for wells with less than the required nine data points.

Table 3.5. Mean parameter values of manure sampled at Fields B and D in October 2010.

Parameter	Field B manure ^z	Field D manure ^z
	----- (kg Mg ⁻¹) -----	
Water	439	476
Dry matter	561	524
NH ₄ ⁺ -N	2.9	2.4
Cl	3.5	1.2
Total C	121	60
Total N	9.8	5.8
Total P	4.6	1.7
Total S	3.6	1.6
Total Na	2.1	0.5
Total K	10.0	4.1
Total Ca	15.1	17.3
Total Mg	4.6	4.3
Total Cu	0.024	0.011
Total Fe	3.9	6.0
Total Mn	0.19	0.20
Total Zn	0.12	0.04

^z Samples were collected October 12, 2010 at Field B and on October 1, 2010 at Field D. Values are expressed on a wet-weight basis (n = 6).

Table. 3.6. Mean soil texture and moisture parameters for Fields A, B, C, and D in early July 2011.

Field	Soil layer (cm)	Texture ^z	Field capacity (mm) ^y	Permanent wilting point (mm) ^y	Measured available soil moisture (mm) ^x	Percent of maximum available moisture capacity (%) ^{w,v}
A	0-25	CL	87	47	44.5	95
	25-50	CL	88	46	47.9	100
	50-75	CL	90	47	38.8	83
	75-100	CL	86	46	41.1	89
	0-100	CL	352	186	172.3	93
B	0-25	SL	55	19	43.8	100
	25-50	SL	55	20	35.4	100
	50-75	SL	53	19	26.5	77
	75-100	SL-LS	51	18	37.7	100
	0-100	SL	214	75	143.3	100
C	0-25	SL	55	19	39.3	100
	25-50	SL	55	19	43.6	100
	50-75	SL	55	20	53.5	100
	75-100	SL	55	20	59.5	100
	0-100	SL	219	77	195.8	100
D	0-25	SL	58	21	27.0	73
	25-50	SL	61	23	47.0	100
	50-75	SL	61	23	49.2	100
	75-100	SL	57	21	55.4	100
	0-100	SL	238	89	178.6	100

^z CL = clay loam, SL = sandy loam, LS = loamy sand.

^y Field capacity and permanent wilting point were calculated based on Saxton *et al.* (1986).

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

^w Maximum available moisture capacity = field capacity – permanent wilting point.

^v Percent of maximum moisture capacity values greater than 100% were set to 100%.

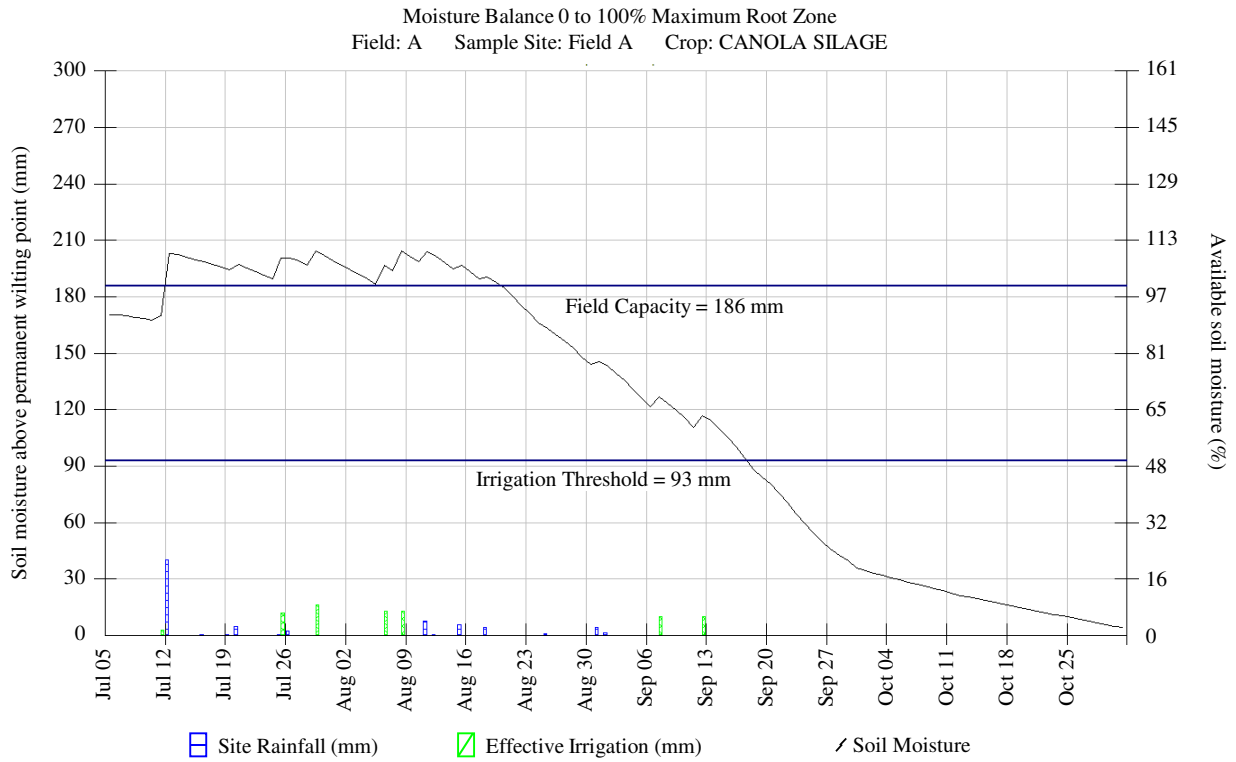


Figure 3.20. Alberta Irrigation Management Model output for Field A in 2011.

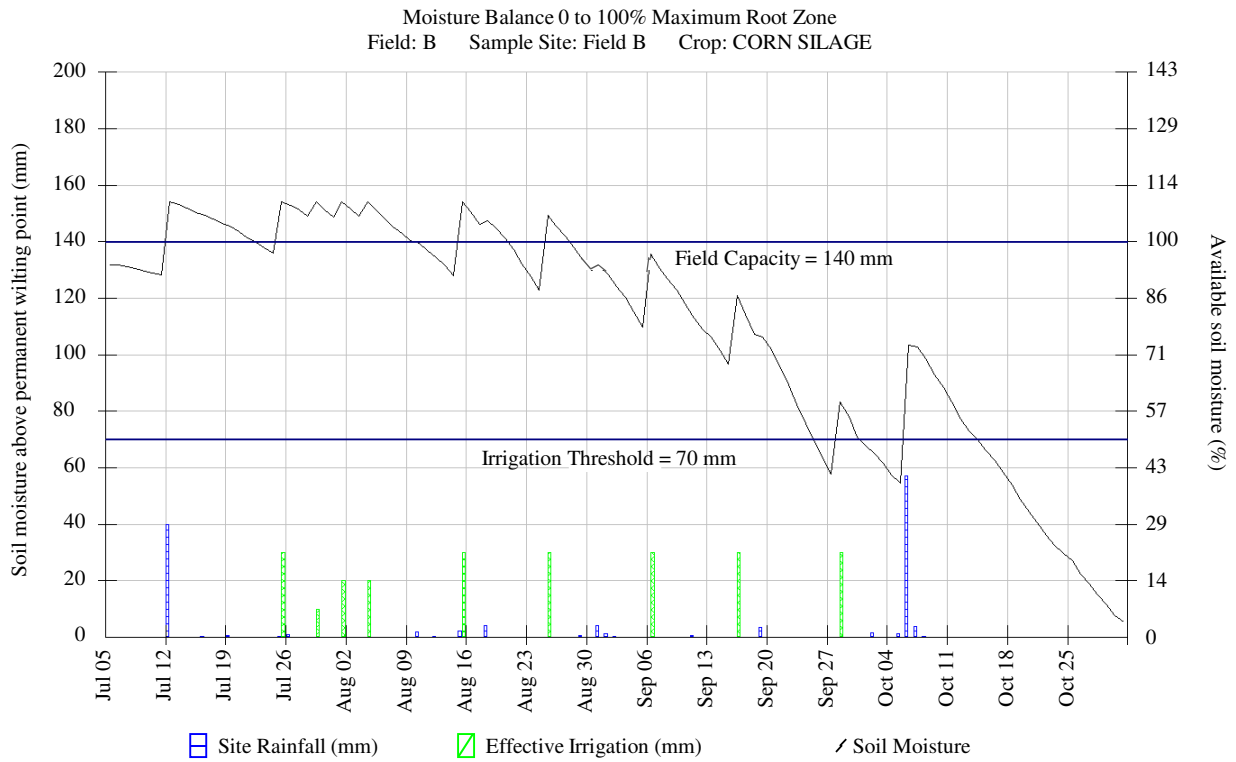


Figure 3.21. Alberta Irrigation Management Model output for Field B in 2011.

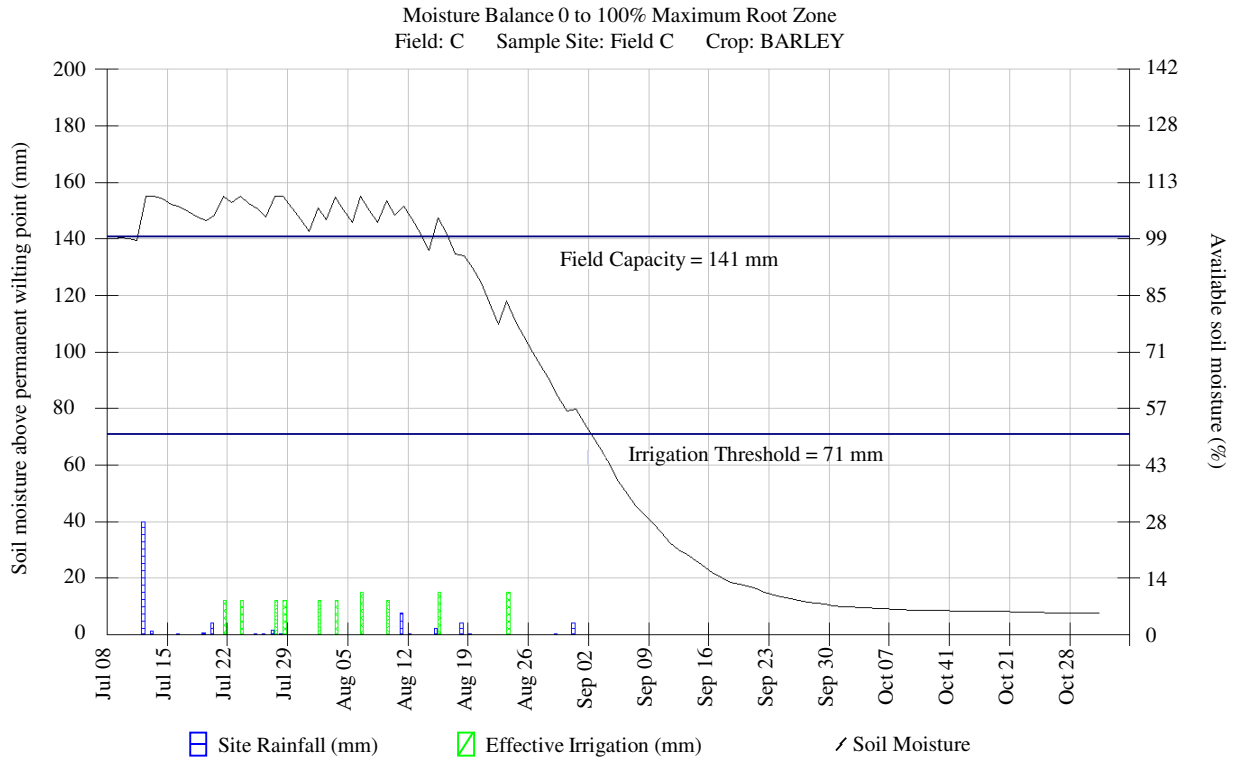


Figure 3.22. Alberta Irrigation Management Model output for Field C in 2011.

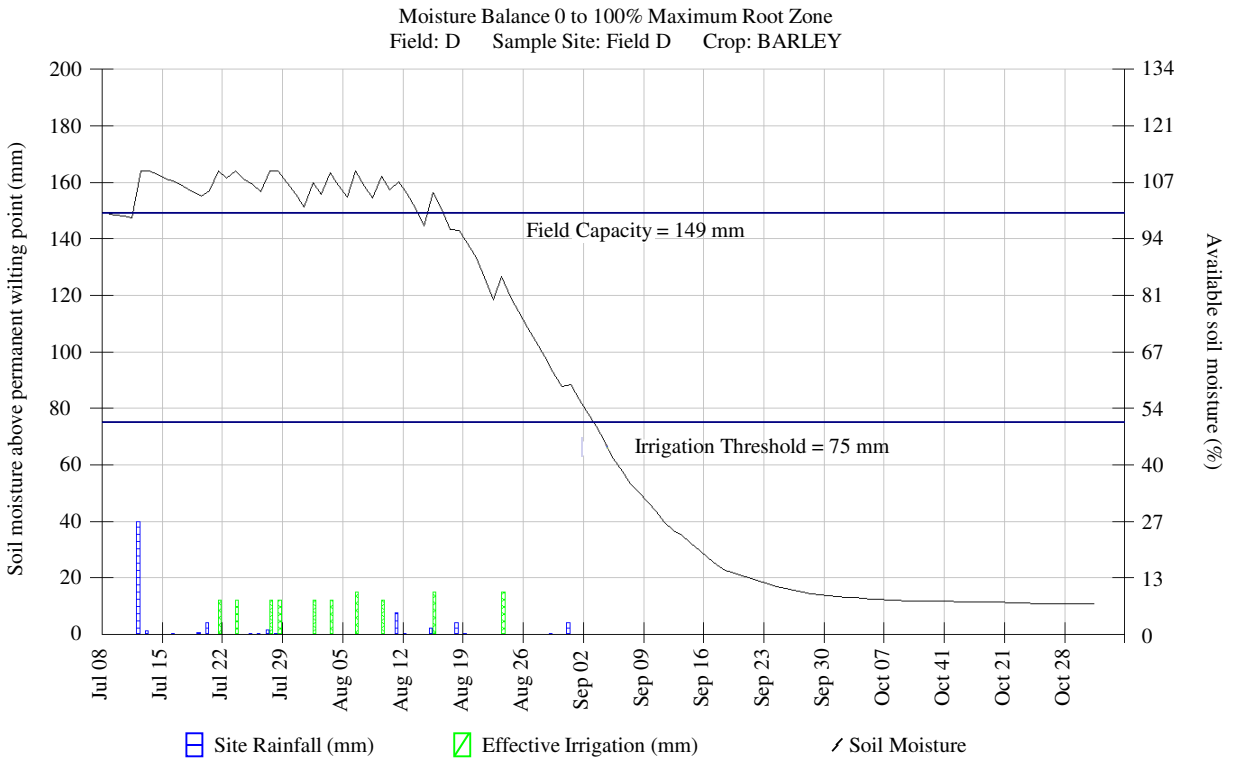


Figure 3.23. Alberta Irrigation Management Model output for Field D in 2011.

3.4 Summary and Future Work

3.4.1 Summary

Four irrigated quarter sections were selected in the Battersea study area to determine the risk of manure spreading on groundwater quality. The field-scale study has two main components: groundwater monitoring and nutrient budget assessment. The fields were selected to represent typical geological conditions in the Battersea area, including a fine-grained soil (Field A), a coarse-grained soil (Fields C and D), and a soil transitional between the fine-grained and coarse-grained soils (Field B). All four fields have a history of beef manure application and the soils contain an excess of STP.

Existing or new water table wells and piezometers on the periphery of the fields were monitored in 2010 and 2011. Fields B, C, and D had existing historical wells; whereas, Field A had no historical wells. Soil core samples were collected from the selected boreholes during well installation. The well design at the fields allowed for the determination of groundwater flow direction, vertical hydraulic gradients, and the upgradient and downgradient concentrations of nutrients in groundwater. In 2011, in-field soil samples to a 3-m depth were collected from each field, and the amount of irrigation water applied was measured.

Horizontal and vertical groundwater flow direction and groundwater quality were examined in 2010 and 2011 at Field A. Groundwater flow direction at the water table was from west to east, with an average depth of 1.3 mbgs. A dynamic response to precipitation, irrigation, and purging and sampling events was observed at the water table well in the northeast corner of the field, with less of a response in the deeper piezometer. Calculations generally showed recharging conditions (downward gradient) in the field. Chloride concentrations in the water table well in the northeast corner of Field A ranged from 16 to 74 mg L⁻¹ (mean: 25 mg L⁻¹), with increasing concentrations in response to increasing groundwater elevation. Nitrate N concentrations in the water table wells were generally near the MMDL. A seasonal pattern was observed for Cl⁻ and NO₃⁻-N with higher concentrations in spring (May and June). Groundwater and soil Cl⁻ and NO₃⁻-N concentrations in the northeast corner of the field increased with depth to 10 mbgs and then concentrations decreased. The cause of the elevated concentrations with depth was not known, but the pattern was not widespread at Field A.

Horizontal and vertical groundwater flow direction and groundwater quality were mainly examined in 2011 at Field B, though some data were collected in 2010. Groundwater flow direction at the water table was to the north, with an average depth of 2.3 m to the water table from the ground surface. Similar to Field A, groundwater elevation was responsive to purging and sampling events. Wells instrumented in the lacustrine deposits showed similar patterns, indicating the lacustrine deposits acted as a single hydrological unit. A general recharging (downward) gradient was found at Field B. Nitrate N concentrations measured in the water table wells in the southwest and southeast corners ranged from 5.4 to 91.0 mg L⁻¹. Chloride concentrations ranged from the MMDL to 125 mg L⁻¹. Nitrate N and Cl⁻ were not present at depth, suggesting transport of manure constituents to depth had not occurred at Field B.

Horizontal and vertical groundwater flow direction and groundwater quality were examined in 2010 and 2011 at Fields C and D. Groundwater flow direction at the water table was from the northeast to southwest and was influenced by a topographic high to the east of the fields. The average depth to groundwater was 2.23 mbgs. Shallow wells in the southeast corner of Field C were in a single hydrostratigraphic unit, and water levels in shallow and deeper wells were generally influenced by precipitation events. Recharging conditions (downward gradient) were generally found at Fields C and D. The highest NO_3^- -N and Cl^- concentrations of all four fields were measured at Fields C and D. Nitrate N concentrations ranged from the MMDL to 79 mg L^{-1} , while Cl^- concentrations ranged from the MMDL to 147 mg L^{-1} . Concentrations were elevated along the western edge of the two fields and were consistent with potential effects of manure spreading. Concentrations were generally low or below the MMDL at depths greater than 8 mbgs; however, in a few wells along the western boundary of the two fields, there was some downward migration of Cl^- . It is not clear if there is localized transport of manure constituents to depth at Fields C and D.

3.4.2 Future Work

The following activities are planned for the field-scale sites:

- 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).
- Hydraulic conductivity testing will be conducted at representative wells at the field sites.
- 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.
- A control field to which manure has not been applied will be identified and instrumented within the stratigraphic regions used in the current study.
- Contaminant transport modeling will be assessed and conducted in future years.