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Nitrate and chloride in groundwater under a beef feedlot in southern Alberta

Jacqueline Kohn

Alberta Agriculture and Forestry, J.G. O'Donoghue Building, #206, 7000 - 113 St., Edmonton, AB, Canada, T6H 5T6. Jacqueline.kohn@gov.ab.ca

Mike Iwanyshyn

Natural Resources Conservation Board, 1910, 250 - 5 St. SW Calgary, AB, Canada, T2P 0R4.

Mike.Iwanyshyn@nrcb.ca

Lynda Miedema

Alberta Agriculture and Forestry, 100, 5401 - 1 Ave. South Lethbridge, AB, Canada, T1J 4V6.

Lynda.Miedema@gov.ab.ca

Barry Olson

Alberta Agriculture and Forestry, 100, 5401 - 1 Ave. South Lethbridge, AB, Canada, T1J 4V6.

Barry.Olson@gov.ab.ca

Andrea Kalischuk

Alberta Agriculture and Forestry, 100, 5401 - 1 Ave. South Lethbridge, AB, Canada, T1J 4V6.

Andrea.Kalischuk@gov.ab.ca

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ABSTRACT A long-term study was initiated in 2010 at a beef feedlot (5000-head) in southern Alberta to investigate the effects of the feedlot on groundwater quality. The study area included residences, pens, feed storage areas and catch basins, all that were constructed prior to current legislative standards. Land-use adjacent to the feedlot consisted of cropland. Evaluation methods included monitoring water levels, groundwater sampling and chemical analysis, trend analysis, and modelling of groundwater flow. Groundwater samples were collected from 13 monitoring wells from 2010 to 2014. The wells were distributed outside the feedlot pens but within or adjacent to the feedlot area. Samples were analyzed for nitrate-nitrogen (NO_3-N) and chloride (Cl). The mean depth to the water table ranged from 0.93 to 2.30 metres below ground surface among the wells. Average concentrations of NO_3-N in wells ranged from less than the detection limit (0.05 mg/L) to 156 mg/L, with an overall average concentration of 44 mg/L. Average concentrations of Cl in wells ranged from less than the detection limit (5 mg/L) to 642 mg/L, with an overall average concentration of 167 mg/L. High NO_3-N and Cl concentrations in the shallow water-table wells suggested potential contamination from manure, while the deeper piezometers (9.5 to 20 mbgs) showed no evidence of manure contamination, having low NO_3-N and Cl concentrations. Temporal analysis of changes in concentrations showed no significant trends for NO_3-N and Cl in the majority of the wells (70%), suggesting that concentrations are not expected to change with time under current management practices.

Keywords: groundwater quality, feedlot, cattle, manure, nitrate-nitrogen, chloride.

INTRODUCTION

The predominance of relatively thick clay aquitards throughout much of the landscape in Alberta and the lack of extensive shallow aquifer suggests that hydrogeologically stable sites are available for siting manure storage and collection facilities, such as feedlots. However, some manure collection and storage facilities may be releasing manure constituents into shallow groundwater (Hendry et al., 2007). Solid beef manure from feedlots is typically stored in pens, on pads, or temporarily stockpiled prior to removal and then applied to the land. Most feedlots typically have catch basins, which store surface-water runoff from facilities (e.g., pens and alleyways). The *Agricultural Operations and Practices Act* (AOPA) provides standards for construction of manure collection and storage facilities (e.g., catch basins) to reduce risk to groundwater quality.

Nitrate-nitrogen (NO_3-N) is a common indicator of groundwater contamination from manure constituents (Maulé and Fonstad, 2000). Generally NO_3-N concentrations higher than 3 mg/L in shallow groundwater may indicate contamination from anthropogenic activity such as livestock production (Forrest et al., 2006). However, NO_3-N may not be the best indicator of manure constituents in shallow groundwater as it can undergo conversion to other nitrogen species. Chloride (Cl) moves readily in water, is typically present at relatively low concentrations under natural conditions, and does not undergo biological transformations or sorb to soil surfaces. These characteristics make chloride a useful indicator for detecting potential groundwater contamination by feedlot manure. Chloride concentrations above 20 mg/L may suggest an anthropogenic origin (Forrest et al., 2006; Lorenz et al., 2014).

There has been limited research on the effects of feedlots on groundwater quality in Alberta (Olson et al., 2005). The objective of this paper was to determine the effects of a beef feedlot on groundwater quality in southern Alberta by monitoring spatial and temporal changes in groundwater NO_3-N and Cl. It is important to note that facilities at the study feedlot (i.e., pens and catch basin) were constructed prior to AOPA regulations, and therefore may not meet current standards, particularly liner requirements for groundwater protection.

MATERIALS AND METHODS

Site description

The beef feedlot site was located in southern Alberta, near Picture Butte. During the study period, the feedlot had approximately 5000-head, and facilities that included pens, feed storage areas, six catch basins (two located south of the pens and four located north of the pens), a dugout, and residences (Figure 1). The feedlot started with 100 to 200 animals when it was constructed in 1974. For purposes of this study, only the two catch basins south of the feedlot were instrumented for groundwater monitoring. Each of these catch basins was approximately 31 m long by 15 m wide. Land use around the feedlot consisted of cropland.

The topography at the site was relatively flat. A local topographic high occurred to the west of the site, with elevation decreasing towards the east and south. There was also an irrigation canal along the property line along the east side (Figure 1).

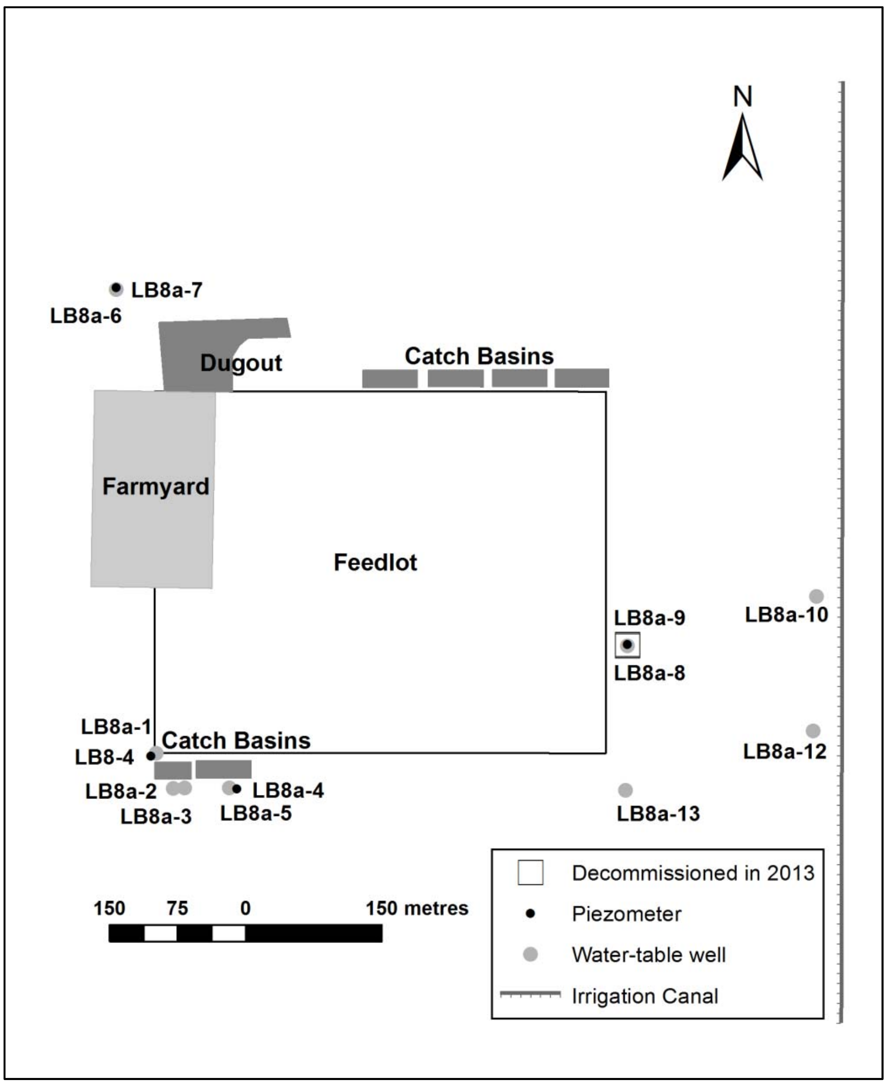

Figure 1. Locations of sampling wells in the study feedlot.

The site was located in a lacustrine basin, between a bedrock high and buried aquifer to the west and an unconfined aquifer of coarse glaciolacustrine sand to the east. Soil at the site consisted primarily of Orthic Dark Brown Chernozems on medium textured sediments deposited by wind and water (Alberta Soil Information Center, 2001). Typical soil textures included loam and silty loam. The Oldman Formation was the uppermost bedrock underlying the site. This site was pre-classified as representing a geological/hydrogeological setting of thick till and clay.

Groundwater wells

A total of 12 groundwater monitoring wells were installed from February 2010 to March 2011: nine water-table wells and three piezometers (Figure 1, Table 1). A historical well, LB8-4, which was part of a regional groundwater study that was conducted in the 1990's (Rodvang et al., 2002), was re-activated in 2012 and was also monitored during the current study. Ground-surface elevations at the wells ranged from 867 to 869 metres above sea level.

Table 1. Summary of monitoring wells installed at the study feedlot.

Name	Type	Total Depth (mbgs)	Depth* to water (mbgs)	Installation Date	Monitored in Current Study
LB8-4	Piezometer	12.2	1.45	1994	Yes
LB8a-1	Water table	3.0	1.23	February 2010	Yes
LB8a-2	Water table	7.1	1.75	February 2010	Yes
LB8a-3	Water Table	7.0	1.75	February 2010	Yes
LB8a-4	Water Table	7.0	1.62	February 2010	Yes
LB8a-5	Piezometer	20.0	1.90	December 2010	Yes
LB8a-6	Water Table	4.8	0.93	March 2011	Yes
LB8a-7	Piezometer	9.8	1.00	March 2011	Yes
LB8a-8	Water Table	6.5	1.92	March 2011	Decom. in 2013
LB8a-9	Piezometer	9.5	2.02	March 2011	Decom. in 2013
LB8a-10	Water Table	4.1	1.95	March 2011	Yes
LB8a-12	Water Table	5.6	1.88	March 2011	Yes
LB8a-13	Water Table	5.7	2.30	March 2011	Yes

* Mean depth from 2010 to 2014.

Single-well response tests (slug or bail tests) were conducted to determine hydraulic conductivity on the majority of the wells at this site. The data were analyzed using the Hvorslev (1951) solution method to calculate hydraulic conductivity values.

Sampling and analysis

Groundwater samples were taken three times per year from 2010 to 2014. A total 193 samples were collected during the study. Prior to sample collection, water levels were measured and wells were bailed (generally at least three well volumes were removed) to ensure samples were representative of current groundwater conditions. Collected samples were stored at less than 4 ºC and were taken to the laboratory and analyzed within 24 hours. Samples were analyzed for several parameters including NO_3-N and Cl.

Temporal trend analysis of NO_3-N and Cl in groundwater samples were analyzed using the Mann-Kendall test (AquaChem software, 2014). Increasing or decreasing trends from 2010 to 2014 were considered significant using a significance level of $P \leq 0.01$. This test does not assume any distribution for the data to determine whether a trend is present, and it is based on the calculation of differences between pairs of successive data.

RESULTS AND DISCUSSION

Site hydrogeology

Outside of the immediate study area, the regional groundwater flow direction was predominantly from the northwest to the southeast, generally following topography (data not shown). At this site, the hydrogeology was more complex, with seasonal and annual fluctuations (Figure 2), and the shallow groundwater flow direction changed during the study period.

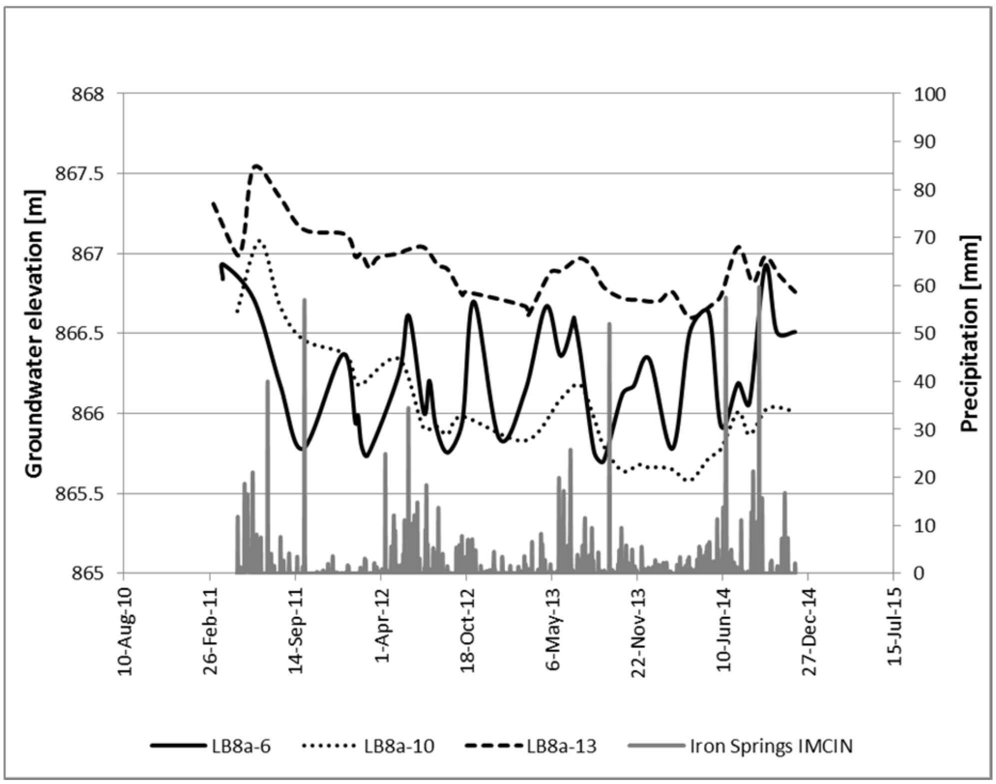

Figure 2. Groundwater elevations measured at water-table wells LB8a-6, LB8a-10, and LB8a-13, and total daily precipitation recorded at the Iron Springs weather station.

The mean depth to water in the monitoring wells ranged from 0.93 to 2.30 metres below ground surface (mbgs) (Table 1). Fluctuations in water-table depth are a result of groundwater response to natural precipitation as well as to irrigation in the region where the feedlot is located. Generally, the direction of shallow groundwater flow at the site was from the south to north, with some east or west components. A general decrease in the water level recorded at the monitoring well LB8a-10 from 2011 to 2014 had a direct effect on the groundwater flow direction at the site during the study period. The decrease in water level was relatively greater at LB8a-10 as compared to other monitoring wells at the site and resulted in a change in the interpreted shallow groundwater flow direction. The groundwater elevation in LB8a-10 was higher compared to LB8a-6 from June 2011 to May 2012. After May 2012, the groundwater elevation was lower in LB8a-10 compared to LB8a-6. With these changes in groundwater elevations, modelling showed that groundwater flow tended to be from south to northeast in 2011 and the first half of 2012; whereas, groundwater tended to flow from the south to northeast and northwest for the majority of the study period (2012 to 2014).

Results from single-well response tests performed at the site showed that horizontal hydraulic conductivity ranged from 10^{-5} (south-east) to 10^{-7} m/s (north-west).

Nitrate-nitrogen and chloride concentrations

Groundwater samples were analyzed for a number of parameters, with the focus of this study on NO_3-N and Cl, which are typical indicators of potential manure contamination of groundwater. General groundwater chemistry is summarized in Table 2.

Table 2. Descriptive statistics of selected measured and calculated parameters.

	Water-table Wells (149 samples from 9 wells)			Piezometers (44 samples from 4 wells)		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Parameter	------------ (mg/L) ------------			------------ (mg/L) ------------		
Chloride	5	642	196	5	167	61
Nitrate-nitrogen	0.1	156.0	56	0.05	0.3	0.1
Bicarbonate	220	1,253	568	415	702	557
Sulphate	50	10,067	3301	208	2666	1299
Calcium	32	651	425	135	523	343
Magnesium	34	1,801	530	34	252	119
Sodium	6	1,717	523	101	563	259
Potassium	2	25	8	6	17	8

The average concentration of NO_3-N from all monitoring wells ranged from below of the detection limit (0.05 mg/L) to 156mg/L, with an overall average of 44mg/L. The average concentration of Cl ranged from below of the detection limit (5 mg/L) to 642mg/L, with an overall average of 167 mg/L. Of the 193 samples, 32% (61 samples) were less than the anthropogenic threshold of 3 mg/L NO_3-N for natural groundwater conditions at the study site. The 32% of samples below the threshold corresponded to five wells (four piezometers and one water-table well, all at LBB8a-12). For Cl, 15% (29 samples) were less than the anthropogenic threshold of 20 mg/L at the site. These samples corresponded to the deepest piezometer (LB8a-5) and water-table well LBB8a-12. Results suggest that only the shallow monitoring wells, and associated shallow groundwater down gradient from the operation were potentially influenced by the feedlot, and not the deeper groundwater or shallow groundwater up gradient from the feedlot (i.e., LB8a-12).

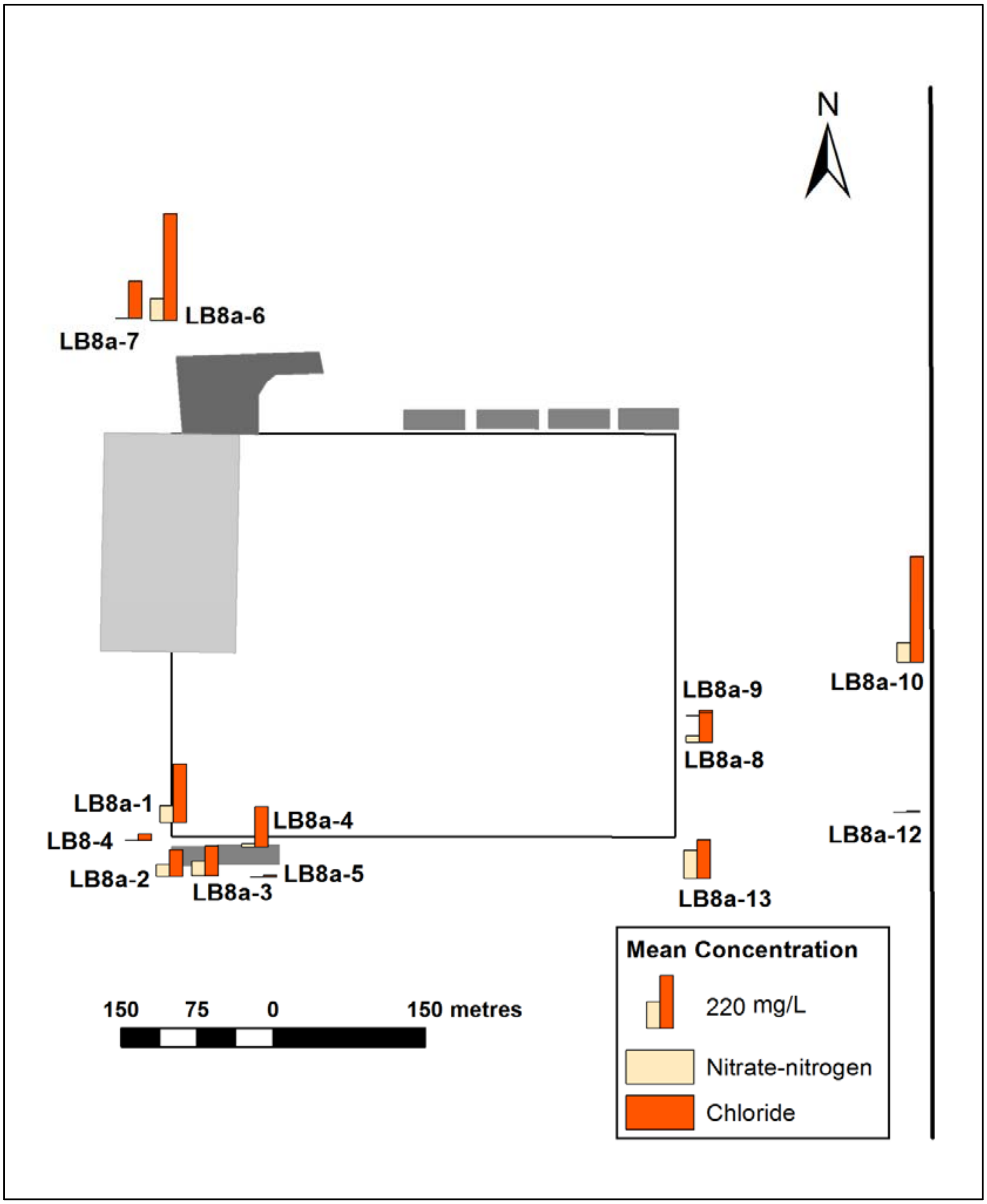

Figure 3. Spatial distributions of the average concentrations of nitrate-nitrogen and chloride per well from 2010 to 2014.

Well LB8a-6, a water-table well down gradient of the feedlot, had some of the highest average concentrations for Cl and NO_3-N (Figure 3). High NO_3-N and Cl concentrations were also measured in LB8a-10, a water-table well down gradient of the feedlot from 2012 to 2014. It was uncertain whether the elevated concentrations in this well came from the feedlot or other activities (e.g., manure spreading) in the area (Lorenz et al., 2014). During a visual inspection of the area in 2015, manure stockpiles were observed along the east boundary of the feedlot, between LB8a-8 and LB8a-10and the manure stockpile may have also influenced groundwater quality, particularly at

LB8a-10. A water-table well (LB8a-12) that was up gradient from the stockpiled manure showed no evidence of Cl contamination and low levels of NO_3-N (ranging from less than the detection limit to 0.53 mg/L).

Trend analyses

Of the 13 monitoring wells, nine wells displayed no significant temporal trend in NO_3-N and Cl concentrations (Figure 4). In the other four wells, NO_3-N concentration significantly increased with time in LB8a-2 and NO_3-N and Cl concentrations significantly increased with time in LB8a-3. The Cl concentrations displayed a significant decrease with time in wells LB8a-1, LB8a-2, and LB8a-7. Well LB8a-3 had a significant upward trend for both parameters, and this well was located close by one of the catch basins at the southwest corner of the feedlot (Figure 1).

As previously indicated, the NO_3-N and Cl concentration results at many of the water-table wells suggest potential contamination of the shallow groundwater from the feedlot. The trend analysis suggested that, in recent years, the concentrations of these two water-quality parameters remained relatively stable. The feedlot has been in operation for about four decades and was built prior to AOPA standards. It may be that the contribution rate of manure contamination has reached steady state or equilibrium, and unless major changes occur at the feedlot, the concentrations in shallow water should remain relatively similar into the future.

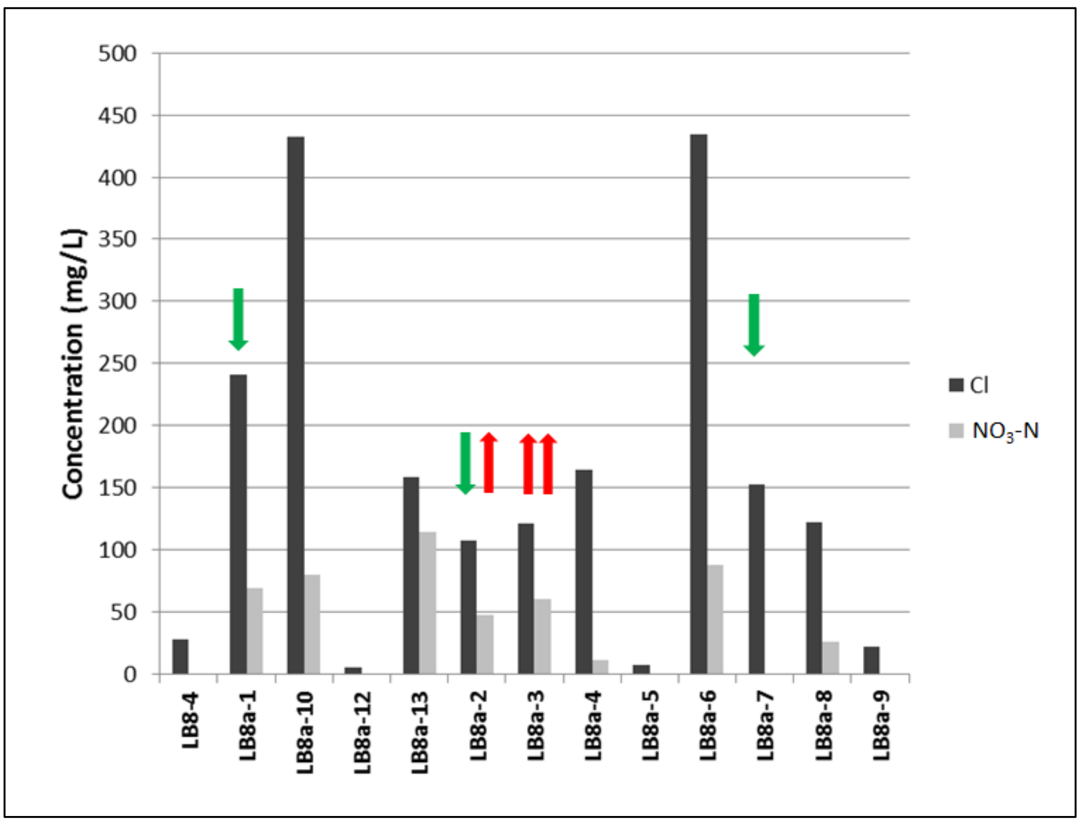

Figure 4. Average NO_3-N and Cl concentrations and temporal trends (arrows) per monitoring well from 2010 to 2014.

CONCLUSION

The concentrations of NO_3-N and Cl in groundwater were monitored at a beef feedlot in southern Alberta from 2010 to 2014. The feedlot was built and in operation a number of years prior to current manure storage and collection regulations. Groundwater levels were shallow, averaging 2.3 mbgs or less in depth among monitoring wells. High concentrations of NO_3-N and Cl in the water-table wells suggested potential contamination from the feedlot. In contrast, deeper piezometers (9.5 to 20 mbgs) showed no evidence of contamination. The Mann-Kendall test displayed no significant temporal trends for NO_3-N and Cl concentration in a majority of the wells (about 70%). The few significant trends observed included increases and decreases in parameter concentrations. Even though the feedlot was likely a contamination source to the shallow groundwater, the contribution rate was relatively stable during the monitoring period and the concentrations are not expected to increase with time under current practices.

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