Shallow groundwater quality at a beef feedlot in southern Alberta

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Kohn, J., M. Iwanyshyn, L. Miedema, B. Olson and A. Kalischuk. 2016. Shallow groundwater quality at a beef feedlot in southern Alberta. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada 58: 1.11-1.19. A 6-yr study (2010–2015) was carried out in southern Alberta to investigate the effects of a beef feedlot (5000 head) on groundwater quality. Evaluation methods included measuring groundwater levels, groundwater sampling and chemical analysis, modelling of groundwater flow, and nitrate-nitrogen (NO₃-N) and chloride (Cl) trend analysis. Groundwater samples were collected from 12 monitoring wells, which were distributed outside the feedlot pens but within or adjacent to the feedlot area and ranged in depth from 4.1 to 20 m. Median concentrations of NO₃-N among the wells ranged from the detection limit (0.05 mg L⁻¹) to 115 mg L⁻¹, with an overall average concentration of 41 mg L⁻¹. Median concentrations of Cl among the wells ranged from the detection limit (5 mg L⁻¹) to 461 mg L⁻¹, with an overall average concentration of 156 mg L⁻¹. The deepest piezometer (20 m) showed no evidence of manure contamination, with NO₃-N less than 3 mg L⁻¹ and Cl less than 20 mg L⁻¹; however, high NO₃-N and Cl concentrations in the shallow water-table wells suggested likely contamination mainly from the feedlot and stockpiled manure. Our results also showed that manure stockpiles might have had a greater effect on groundwater quality than the feedlot itself. Temporal analysis of changes in concentrations showed no significant trends for NO₃-N and Cl in the majority of the wells (75%), suggesting that concentrations are not expected to change with time under current management practices at this site. Keywords: groundwater quality, feedlot, cattle, manure, nitrate-nitrogen, chloride.

INTRODUCTION

The production and management of manure from feedlots and other confined feeding operations may be a concern for groundwater quality. Alberta had about 5.46 million head of cattle in 2014, representing approximately 41% of the Canadian beef herd (AAF 2015a). This includes about 143 feedlots with one time average capacity of more than 1000 head per feedlot and a total capacity of about 1.3 million head (CanFax 2015). The predominance of relatively thick clay aquifers throughout much of the landscape in Alberta and the lack of extensive shallow aquifers suggests that hydrogeologically stable sites are available for siting manure storage and collection facilities, such as feedlots, pens and catch basins. However, it has been suggested that some manure collection and storage facilities in Alberta may be releasing manure constituents into shallow groundwater (Hendry et al. 2007).

Solid manure from beef feedlots is typically stored in pens, on pads, or temporarily stockpiled, and then applied to cropland. Most feedlots typically have catch basins, which store surface runoff from facilities (e.g., pens and alleyways). Beginning in 2002, the Agricultural Operation Practices Act (AOPA) provides standards in Alberta for manure collection and storage facilities and manure application to reduce risk to surface water and groundwater quality from manure management activities. However, operations that were constructed prior to 2002 and have not expanded or made significant changes may not meet current standards.

Nitrate-nitrogen (NO₃-N) is a common indicator of groundwater contamination from manure constituents (Maulé and Fonstad 2000) and a water quality parameter of concern related to human health effects, such as...
methemoglobinemia (WHO 1998). Generally, NO$_3$-N concentrations greater than 3 mg L$^{-1}$ (i.e., anthropogenic threshold) in shallow groundwater in Alberta may indicate contamination from anthropogenic activities such as livestock production (Forrest et al. 2006; Madison and Brunett 1985). However, NO$_3$-N may not always be the best indicator of manure constituents in shallow groundwater, as it can undergo conversion to other N species and can come from several other sources (e.g., septic tanks, chemical fertilizer).

Chloride (Cl) is typically used as a conservative tracer for potential contamination from manure (Redding 2016; McCallum et al. 2008; Fonstad 2004; Ham 2000; Krapac et al. 2000; Maulé and Fonstad 2000), as it is readily mobile in water and does not undergo biological transformations or sorb to soil surfaces. Chloride in Alberta groundwater is typically low, while Cl concentrations in feedlot manure and runoff are relatively higher (Hendry et al. 2007; Olson et al. 2002). Chloride concentrations of more than 20 mg L$^{-1}$ (i.e., anthropogenic threshold) in Alberta groundwater may suggest contamination from anthropogenic activities (Forrest et al. 2006; Lorenz et al. 2014).

There has been limited research on the effects of manure management activities at feedlots on groundwater quality in Alberta (Miller et al. 2008; Olson et al. 2005; Riddell and Rodvang 1992; Sommerfeldt et al. 1973) and throughout the world (Sahoo et al. 2016; Smoron 2016; Harter et al. 2014). Research regarding the effects caused by active feedlots shows contrasting conclusions. Some studies have found that nitrate levels beneath feedlots are negligible (Gbolo and Gerla 2013; Miller et al. 2008; Ellis et al. 1975; Mielke et al. 1974), whereas, other studies have found high levels immediately beneath the surface or at depth (Maulé and Fonstad 2002; Maulé and Fonstad 2000; Riddell and Rodvang 1992) or hydraulically down-gradient from the feedlot (Hunter 2013; Coote and Hore 1979).

Studies conducted at a research feedlot in southern Alberta for 3 years by Olson et al. (2005) showed that the feedlot generally did not affect NO$_3$-N concentration in the groundwater; however, Cl concentrations strongly suggested that manure constituents from the feedlot had moved into the shallow groundwater.

Other studies have suggested that low-permeability layers may form as wet manure accumulates in active feedlot pens, and this can prevent infiltration and reduce seepage rates to groundwater (Gbolo and Gerla 2013; Mielke et al. 1974). The physical process of compaction by cattle also contribute to the self-sealing of soils in active feedlot pens (Miller et al. 2008). The compacted organic layers that form can reduce contaminant leaching, even in moderately coarse and coarse-textured soils (McCullough et al. 2001; Dantzman et al. 1983; Campbell and Racz 1975). Self-sealing of soils below the manure pack in feedlot pens is attributed to initial physical blockage of soil pores by manure solids, followed by the development of a microbial growth layer, and these processes are enhanced by the higher organic carbon levels in manure (Miller et al. 2008; Hendry et al. 2007; Rowsell et al. 1985). However, when the manure pack in pens dries, this layer may shrink and crack and allow water to infiltrate rapidly (Mielke et al. 1974), promoting nitrate leaching. Mielke and Ellis (1976) found that the nitrate content of groundwater under abandoned feedlots was 5.6 and 6.5 times greater than under active feedlots and cornfields, respectively.

The objective of this study was to determine the effects of an active beef feedlot on groundwater quality in southern Alberta by determining spatial and temporal changes in groundwater quality using NO$_3$-N and Cl as indicators. This study focused on the contributions from the site (i.e., relative concentrations differences between up- and down-gradient locations in relation to the feedlot).

**MATERIALS AND METHODS**

**Site description**

The site was a 5000-head capacity beef feedlot located near Picture Butte, Alberta, Canada, in the Lethbridge Northern Irrigation District. Facilities at the site included pens, feed storage areas, six catch basins (two south and four north of the pens), a dugout, and residences (Fig. 1). Most of the catch basins were 30 m by 15 m and 3.5 m deep, although the useable depth was approximately 2 m. An irrigation canal was present along the east side of the site and typically conveyed water from early May to early

Fig. 1. Site diagram and monitoring well locations.
October. Land use surrounding the feedlot was irrigated cropland. Throughout the study, temporary and recurrent manure stockpiles of about 1 m in height were observed at the southeast corner of the site (Fig. 1). Manure piles about 2 m high were also observed to the east of the feedlot and remained in place throughout the study.

Topography at the site was relatively flat with a local topographic high west of the site and decreasing elevation towards the east and south.

The site was 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 Centre 2001). Typical soil textures were loam and silty loam. The Oldman Formation was the uppermost bedrock underlying the site.

The site was located in a region with extensive irrigation and a high density of confined feeding operations, particularly beef feedlots, where a regional groundwater monitoring transect of 115 wells was installed in 1993 and 1994 and sampled from 1994 to 2001 by Rodvang et al. (1998, 2002), and partially reactivated from 2009 to 2015 (Kohn et al. 2016; Lorentz et al. 2014).

It is important to note that facilities at the study feedlot (i.e., pens and catch basins) were constructed prior to AOPA regulations, and therefore, may not meet current standards, particularly liner requirements for groundwater protection.

**Groundwater wells**

A total of 12 groundwater monitoring wells were used in this study (Table 1). Eleven wells were installed from February 2010 to March 2011: eight water-table wells and three piezometers.

An existing piezometer (LB8-4), which was part of a previous regional groundwater study (Rodvang et al. 2002), was re-activated in 2012 and also monitored during the current study (Fig. 1; Table 1). All the water-table wells had screen intervals of 3 m and the piezometers had 0.5-m screens. Surface elevations at the wells ranged from 867 to 869 metres above mean sea level (mamsl).

The wells were installed around the immediate peripheral of the feedlot with the intent of isolating the contributions from the feedlot by intercepting up-gradient and down-gradient groundwater. Up-gradient wells represented background conditions, and relative comparisons to down-gradients wells were used to determine whether or not the feedlot was a source of contamination to the groundwater.

**Sampling and analysis**

Groundwater samples were taken generally three times per year from 2010 to 2015; however, not all wells were sampled each time depending on available resources and circumstances. A total of 191 samples were collected during the study. Prior to sample collection, water levels were measured and wells were purged (generally three well volumes were removed or until the well was dry, whichever occurred first) and allowed to fully recover to ensure representative samples of current groundwater conditions. Collected samples were stored in ice coolers at 4 °C and transported to the Alberta Agriculture and Forestry laboratory and analyzed for several parameters within 24 h. Water samples were filtered (0.45 μm) and analyzed for concentrations of NO$_3$-N (Quantitative determination of nitrate and nitrite by air-segmented continuous flow-analysis; APHA et al. 1995) and Cl (Quantitative determination of Cl based on potentiometric titration of H$_2$O$_2$; APHA et al. 1995).

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

**Analysis**

An interactive finite element model (FEFLOW, Mike powered by DHI) was used to describe the system and analyse groundwater flow patterns (Diersch 2004) based...
on 5 years (2011–2015) of measured groundwater elevations and calculated horizontal hydraulic conductivities. The 2010 data were not used because data from only 4 wells were available (Table 1).

The Mann-Kendall test (AquaChem software, powered by Waterloo Hydrogeologic 2014; Kendall 1975; Mann 1945) was used for temporal trend analysis of NO₃-N and Cl. A significance level of $P \leq 0.05$ was used to identify significant increasing or decreasing trends from 2010 to 2015. 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 values. Trend direction and strength was estimated using the Sen’s slope estimator (median annual change in concentration, i.e., mg L⁻¹ yr⁻¹) and the relative trend slopes, calculated by dividing the slope by the median concentration and multiplying by 100.

**RESULTS AND DISCUSSION**

**Site hydrogeology**

The mean elevation of water in monitoring wells ranged from 866.01 to 866.88 mamsl, with associated mean water-table depths ranging from 0.96 to 2.33 metres below ground surface (mbgs) (Table 1). Fluctuations in water-table depth were the result of shallow groundwater responses to natural processes (i.e., precipitation, runoff, snowmelt, infiltration, evapotranspiration) and to other activities such as irrigation in the region where the site was located (Fig. 2). From 2011 to 2015, mean annual precipitation recorded at the Iron Springs weather station, approximately 4 km northwest of the site, was 356 mm yr⁻¹ (AAF 2015b).

The groundwater flow direction in the study region was predominantly from the northwest to the southeast, generally following the regional topography (data not shown) (Lorenz et al. 2014). At the site scale the hydrogeology was more complex, with seasonal and annual fluctuations (Fig. 2) and with apparent changes in shallow groundwater flow direction.

A general decrease in water level from 2010 to 2015 was observed at all the water-table wells. The decrease was greater at LB8a-10 as compared to LB8a-6 (Fig. 2), and this resulted in a change in shallow groundwater flow direction interpretations. Generally, the direction of shallow groundwater flow at the site was from the south to north, with some east or west components (Fig. 3). Based on modelling, groundwater flow tended to be from southeast to northwest in 2011 and the first half of 2012. Groundwater flow tended to be from the south to northeast and northwest for the majority of the study period (2012 to 2015). Although the flow direction changed at the feedlot, wells LB8a-13 and LB8a-12 were the most up-gradient wells at this site for the entire study period.

Single-well response tests resulted in calculated horizontal hydraulic conductivity values ranging from $10^{-5}$ (southeast) to $10^{-7}$ m s⁻¹ (northwest). This correlated with drill logs, which showed relatively more sandy material on the east side of the site.

**Nitrate-nitrogen and chloride concentrations**

The concentration of NO₃-N from all samples ranged from the detection limit (0.05 mg L⁻¹) to 156 mg L⁻¹ (Table 2), with a median of 37 mg L⁻¹ for the 191 samples. For NO₃-N, 64% (123 samples) had NO₃-N concentrations greater than the associated anthropogenic threshold of 3 mg L⁻¹ and were observed at seven relatively shallow (<7.2 m)

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**Table 2. Descriptive statistics for nitrate-nitrogen and chloride concentrations in groundwater samples from 2010 to 2015.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Water-table Wells</th>
<th>Piezometers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(141 samples from 8 wells)</td>
<td>(50 samples from 4 wells)</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>Max.</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>&lt;0.05</td>
<td>156</td>
</tr>
<tr>
<td>Cl</td>
<td>&lt;5</td>
<td>642</td>
</tr>
</tbody>
</table>

SD: standard deviation.
Thirty-six percent of all samples (68 samples) had NO$_3$-N concentrations less than 3 mg L$^{-1}$, corresponding to five wells: four piezometers and one water-table well. The median concentration of the eight water-table wells (4.1–7.1 mbgs) was more than 500-fold higher than the deeper (9.5–20 mbgs) piezometers (Table 2). Water-table wells that contained high (4–50 mg L$^{-1}$) and very high (51–115 mg L$^{-1}$) NO$_3$-N concentration were distributed throughout the site (Fig. 4). Up-gradient well LB8a-12, in the southeast corner of the site, was the only water-table well that had NO$_3$-N concentrations less than 3 mg L$^{-1}$ for every sampling event.

The spatial variation of NO$_3$-N concentrations in the water-table wells was consistent with previous findings reported by Maulé and Fonstad (2000) that showed groundwater immediately adjacent to or under feedlots had NO$_3$-N concentrations from 1 to 140 mg L$^{-1}$. Maulé and Fonstad (2002) also reported findings by Robertson et al. (1974), who found that 15 feedlots in central Alberta had considerable amounts of NO$_3$-N in groundwater down to 3-m depth. In the current study, no contamination by NO$_3$-N was found at the 20-m depth, and the depth to the water table was from 0.96 to 2.33 m, similar to depths reported by Olson et al. (2005) at a research feedlot near Lethbridge, Alberta. Ellis et al. (1975) reported values of NO$_3$-N from 0.1 to 38.6 mg L$^{-1}$ in Nebraska, United States, where the average depth to the water table was 8.5 m.

The lateral extent of effects from the feedlot was observed in shallow groundwater as far as 200 m down gradient from feedlot facilities with NO$_3$-N levels ranging from 21 to 156 mg L$^{-1}$, which was greater than the lateral extent previously observed in other studies in northeastern Colorado, USA and in Ontario, Canada (Hunter 2013; Coote and Hore 1979).
The concentration of Cl ranged from the detection limit (5 mg L\(^{-1}\)) to 642 mg L\(^{-1}\) (Table 2), with a median of 135 mg L\(^{-1}\) for the 191 samples. For Cl, 17% of the samples (33 samples) were less than the anthropogenic threshold of 20 mg L\(^{-1}\) corresponding to the deepest piezometer (LB8a-5) and water-table well LBB8a-12, while 83% of the samples were greater than 20 mg L\(^{-1}\) (Fig. 5).

Seasonal patterns were displayed for NO\(_3\)-N and Cl concentrations at some wells. For example, concentrations at LB8a-6 decreased from spring to fall and then increased from fall to spring. However, no correlation with the groundwater levels was clearly identified (data not shown).

Water-table wells LB8a-6 and LB8a-10, located down gradient of the feedlot, displayed some of the highest median concentrations for Cl and NO\(_3\)-N (Figs. 4 and 5), suggesting the feedlot was affecting the shallow groundwater. This was supported by the fact that these concentrations were higher than the concentrations obtained in the up-gradient well LB8a-12 (where NO\(_3\)-N was < 1 mg L\(^{-1}\) and Cl was < 5 mg L\(^{-1}\)). Well LB8a-6, the most down-gradient water-table well from the feedlot, showed a very strong linear correlation between NO\(_3\)-N and Cl concentrations (r=0.98), consistent with a single source, such as manure. Wells LB8a-6, LB8a-8, and LB8a-10 had comparable NO\(_3\)-N/Cl ratios, suggesting that the NO\(_3\)-N and Cl originated from similar sources potentially manure at the feedlot.

The manure stockpiles at the site (Fig. 1) may have affected the groundwater quality. Well LB8a-13, had the highest concentrations of both parameters as well as the highest hydraulic head at the site. The stockpiled manure was often very close to this well, and on occasion, manure surrounded the wellhead. The stockpiled manure may have also influenced shallow groundwater quality near LB8a-10, given the estimated groundwater flow based on calculated hydraulic heads (Fig. 3), and the stockpiles were between these two wells (Fig. 1). Well LB8a-10 may have received contributions from the feedlot and manure stockpiles (i.e., more than one source), and this may explain the lower concentrations between NO\(_3\)-N and Cl (r = 0.65) compared to wells LB8a-8 (r = 0.87) and LB8a-6 (r = 0.98).

Well LB8a-12 up gradient with respect to shallow groundwater flow from the feedlot and most of the stockpiled manure, but down gradient of LB8a-13 and possibly some of the stockpiled manure showed no evidence of NO\(_3\)-N and Cl contamination in the shallow groundwater (Figs. 4 and 5). It is possible that a potential plume emanating from the stockpiled manure near LB8a-13 may not have migrated toward LB8a-12 or its migration was not extensive enough to reach this well. The plume may have been moving northeast, with dispersion and advective transport that occurred more north than east, resulting in the observed high concentrations at LB8a-8 and LB8a-10, and not LB8a-12.

Because of the position of well LB8a-13 and the flow direction of groundwater (Fig. 3), well LB8a-13 did not have an obvious up gradient or control well. This may limit the ability to interpret the results for this well. However, based on the site characteristics and the results from the other wells, particularly well LB8a-12, up-gradient groundwater from well LB8a-13 likely contained NO\(_3\)-N and Cl concentrations similar to well LB8a-12.

Based on these results, it appears that the feedlot pens may pose a relatively lower risk for groundwater contamination than the stockpiled manure at this site, supporting the results reported in the literature that an organic compacted layer that forms in active pens may limit downward movement; however, this would not be the case under the area with stockpiled manure, as compaction would not be prevalent in this area.

Shallow wells near the catch basins in the southwest part of the site also showed evidence of contamination from manure constituents (Figs. 4 and 5). In contrast, the two deepest piezometers (LB8a-4 and LB8a-5) at the site (Table 1) had low concentrations of NO\(_3\)-N (Fig. 4). In the oldest well (LB8a-4), which was the shallowest of the two piezometers, Cl concentrations of all the samples were slightly more than 20 mg L\(^{-1}\); however, these samples were less than the historic mean (1994 to 2001) of 41.3 mg L\(^{-1}\) reported by Rodvang et al. (1998).

**Trend analysis**

Of the 12 monitoring wells, nine displayed no significant temporal trends for NO\(_3\)-N and Cl concentrations (Table 3). Three monitoring wells displayed a significant trend in one or both parameters.

The concentration of NO\(_3\)-N significantly increased with time in LB8a-2 and LB8a-3 (Table 3), which were water-table wells near the catch basins at the southwest corner of the feedlot (Fig. 4). Well LB8a-3 also had a significant increasing trend in the Cl concentration and a strong correlation between both parameters (r=0.91). Both wells also had comparable NO\(_3\)-N/Cl ratios suggesting the same origin.

The concentration of Cl significantly decreased with time in the down-gradient piezometer LB8a-7, which was the most down gradient piezometer at the feedlot, suggesting a change in the source contributions with depth over time.

The relative trend slopes ranged from 9.6 to 13.2 % yr\(^{-1}\) for NO\(_3\)-N and from -4.3 to 5.4 % yr\(^{-1}\) for Cl (Table 3). Because relatively few wells displayed significant temporal trends, this suggests in recent years the concentrations of NO\(_3\)-N and Cl have remained relatively stable at this site.

These findings appear consistent with results from a regional study conducted in the Battersea area, which included the feedlot from the current study, where no significant trends in NO\(_3\)-N and Cl concentrations were observed on a regional scale from 1999 to 2014 (Kohn et al. 2016).
Although the feedlot likely affected shallow groundwater quality, the contribution was relatively stable during the monitoring period and appears to have reached a steady state. No significant temporal trends were observed for NO$_3$-N and Cl concentrations in a majority of the wells (about 75%). The few observed increasing trends were localized near the catch basins. This suggests that concentrations of NO$_3$-N and Cl are not expected to change in the future under current practices at this site.

Manure stockpiles were attributed to have had a greater potential effect on groundwater quality than the feedlot pens — the monitoring well located beside the stockpiles had the highest NO$_3$-N concentration at the feedlot site. This study helps clarify the magnitude of concerns with regards to manure management and shallow groundwater contamination from the livestock industry.

It is expected that livestock practitioners and policy makers will be able to identify opportunities for improved manure management strategies to mitigate negative effects on groundwater.

### ACKNOWLEDGEMENTS

Resources for this study were provided by Alberta Agriculture and Forestry (AAF), the Natural Resources Conservation Board (NRCB), and the Alberta Irrigation Projects Association. We acknowledge the cooperation of local producers. In addition, we thank AAF and NRCB colleagues for assistance and coordination with the field work, and the AAF laboratory in Lethbridge, Alberta for groundwater sample analyses.

### REFERENCES


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### Table 3. Trends in nitrate-nitrogen (NO$_3$-N) and chloride (Cl) concentrations from 2010 to 2015.

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Depth (m)</th>
<th>Median NO$_3$-N (mg L$^{-1}$)</th>
<th>Overall Trend</th>
<th>Sen's slope (mg L$^{-1}$ yr$^{-1}$)</th>
<th>Relative slope (% yr$^{-1}$)</th>
<th>Median Cl (mg L$^{-1}$)</th>
<th>Overall Trend</th>
<th>Sen's slope (mg L$^{-1}$ yr$^{-1}$)</th>
<th>Relative slope (% yr$^{-1}$)</th>
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<tr>
<td>LB8a-10</td>
<td>4.1</td>
<td>79.74</td>
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<td>--</td>
<td>--</td>
<td>460.89</td>
<td>--</td>
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<tr>
<td>LB8a-6</td>
<td>4.8</td>
<td>79.73</td>
<td>--</td>
<td>--</td>
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<td>LB8a-13</td>
<td>5.7</td>
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<td>163.09</td>
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<td>9.6</td>
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<td>152.45</td>
<td>D</td>
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<td>LB8-4</td>
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<td>5.00</td>
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I = significant increasing trend.
D = significant decreasing trend.


