Impacts of cattle penning on groundwater quality beneath feedlots

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Maulé, C.P. and Fonstad, T.A. 2000. **Impacts of cattle penning on groundwater quality beneath feedlots.** Can. Agric. Eng. 42:087-093. The groundwater quality of five 20 to 35 year old cattle feedlots around Saskatoon were investigated. Water samples were obtained from 30 piezometers (2.5 to 14.5 m deep) during three sample times (February, June, and August of 1997). All piezometers were located outside the feedlot pens but within or adjacent to the feedlot area. The objective of this study was to determine whether shallow groundwater within the feedlot area is contaminated by feedlot manure. Elevated concentrations of the following ions were found to indicate the presence of manure in groundwater; K^+, Cl^-, NO_3-N, NH_4-N, and total dissolved P. Due to the absence of baseline data, two different levels of concentration were used; a lower level to divide waters between 'background' and those with perhaps some indication of agricultural activity (i.e. poor fertilizer management); and an upper level to indicate the definite presence of feedlot manure. Of the five sites, four displayed concentrations indicative of feedlot manure. Of the 30 piezometers, only two had low concentrations that could be considered background, that is showing no indication of being affected by any human activity. The high degree of groundwater contamination as evidenced by the piezometers, could be a function of the shallow levels, only eight piezometers had water levels deeper than 4 m.

La qualité de l'eau sous-terraine de cinq parcs d'engraissement datant de 20 à 35 ans, dans les environs de Saskatoon a été étudiée. Des échantillons d'eau ont été obtenus à partir de 30 piézomètres (2.5 à 14.5 m de profondeur) à trois périodes d'échantillonnage (février, juin et août 1997). Tous les piézomètres étaient situés à l'extérieur des enclos d'engraissement mais à l'intérieur ou adjacent au périmètre délimitant l'enclos. L'objectif de cette étude était de déterminer si l'eau sous-terraine peu profonde à l'intérieur de la région du parc d'engraissement était contaminée par le fumier de l'enclos. Des concentrations élevées des ions suivants, K^+, Cl^-, NO_3-N, NH_4-N et P total dissout, ont été trouvées indiquant la présence de fumier dans l'eau sous-terraine. Dû à l'absence de données de base, deux différents niveaux de concentration ont été utilisés; un niveau moins élevé pour diviser les eaux entre "sous-terraine" et celles avec indication de possible activité agriculturale (ie utilisation pauvre de fertilisants); et un niveau plus élevé pour indiquer la présence assurée de fumier du parc d'engraissement. Parmi les cinq sites, quatre démontraient des concentrations indiquant la présence de fumier du parc d'engraissement. Parmi les 30 piézomètres, seulement deux avaient des concentrations faibles pouvant être considérées comme bruit de fond, qui ne montraient aucune indication d'avoir été affectés par toute activité humaine. Le degré élevé de contamination de l'eau sous-terraine, tel que montré par les piézomètres, pourrait être dû aux niveaux peu profonds , seulement huit piézomètres avaient des niveaux d'eau plus profonds que 4 m.

INTRODUCTION

Relevance and objective

In Western Canada, feedlots are the primary means of finishing for beef cattle production. In feedlots, cattle are kept in open-air pens with earthen floors and mixed feed portions, containing other ingredients, are brought to them. The feedlot system is efficient and economical, given Western Canada's space and climate. However, there is the potential for groundwater quality deterioration from seepage through the pen floors and from inadequately controlled runoff waters. Given the size and growth potential of the industry, concerns have been expressed for more stringent environmental regulation of new feedlots.

The main indicator of groundwater contamination from feedlots, or any agricultural operation, has been nitrates, although ammonia is also a commonly reported parameter in feedlot groundwater studies (Drommerhausen et al. 1995; Coote and Hare 1978; Mielke 1974; Elliott et al. 1973; Sommerfeldt et al. 1973; Gilbertson et al. 1971; Watson 1971). Chloride and sodium solutes have also been used to trace groundwater contamination from feedlots (Norstadt and Duke 1983; Coote and Hare 1978) or immediately beneath pen floors (Norstadt and Duke no date; Elliott et al. 1973). Elevated phosphorous is a concern in surface waters as it causes algae blooms. Although nitrate is an immediate concern for drinking water quality, it is not a suitable early indicator of the presence of seepage waters from feedlots as it undergoes conversion to other nitrogen species or becomes immobile upon biological uptake. Other solutes, such as chloride and potassium could also be used to indicate whether feedlot manure has contaminated groundwaters.

During 1996 to 1997 a preliminary study of five 20 to 35 year old Saskatchewan feedlots was conducted with the purpose of determining whether manure seepage has reached underlying groundwater. Manure seepage can be characterized by high concentrations of certain types of ions (e.g., NH_4^+-N, K^+, Cl^-). Some of these ions may be naturally present in groundwater (e.g., K^+, Cl^-) and nitrates may be present from other agricultural sources (e.g., improper fertilizer management) thus determination of the presence of manure seepage must be done by comparison to background concentrations of the groundwater.

The specific objective of this paper is to determine whether groundwaters within or immediately adjacent (within 100-200 m) of feedlot pens and runoff collection storages show evidence of contamination by feedlot manure through elevated

Table I. Prairie groundwater and beef manure chemistry.

Type	Parameter	EC mS/cm	Na^+ mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	K^+ mg/L	Cl^- mg/L	SO_4^{2-} mg/L	n
1	mean	0.6	20	100	34	6	20	71	41
	CV	35	72	42	52	77	132	74	
2	mean	2.0	125	259	142	13	67	929	43
	CV	68	100	53	95	104	109	99	
3	mean	3.6	592	257	187	13	229	1831	11
	CV	54	60	55	74	74	72	62	
manure		NA	310	850	420	2900	NA	NA	

Groundwater values are from averages of data from Saskatchewan groundwater samples (Rutherford 1966; Saskatchewan Environment 1975; Fortin et al. 1991)
CV - coefficient of variation expressed as percent.
NA - Not Available
n - number of samples
Manure values are soluble concentrations from beef fresh manure (Gilbertson et al. 1979).

concentrations of certain ions. This objective was met through a drilling program that obtained soil samples and established piezometers for monitoring groundwater chemistry. Due to the lack of groundwater baseline data and feedlot use records, no attempts at explaining the mechanisms of how the contaminants got to their location are provided in this paper. Information from this study will be available for the establishment of more detailed investigative studies.

'Typical' groundwater and feedlot manure chemistry

To properly assess whether a surface contaminant has reached a certain location within the groundwater flow system, it is necessary to have baseline information about the groundwater chemistry. Most solutes present in manure are also present in lesser concentrations within natural (uncontaminated) groundwaters, thus to evaluate the presence of manure, the type and concentrations of naturally occurring solutes must be known. Solute type and concentration within native groundwater conditions will vary with the type of geology, soil chemistry, the depth of the water flow system, the length of the flow path, and the time spent by the water in the flow system. In the Canadian Prairies, shallow groundwater chemistry generally is reflective of climate and soil conditions in recharge zones and reflective of geological conditions in discharge zones. Type 1 waters are recent recharge precipitation waters located within shallow till systems and tend to be low in total dissolved solids (TDS) with high Ca/Mg or Ca/Na ratios. Type 2 waters are higher in TDS with Ca^{2+}, Mg^{2+}, and sulphates being the dominant ions. Type 3 waters are high in TDS with Na^+, Cl^- and SO_4^{2-} being dominant ions. Type 3 waters generally represent discharge sites or groundwaters originating from marine shale bedrock. Marine shale underlies the till and where this shale is shallow or the flow systems have come in contact with the shale, groundwaters tend to be dominated by Na^+ and Cl^- ions with low Ca/Na ratios (Freeze and Cherry 1979; Rutherford 1966). Most of the groundwater systems within surficial materials (top 30 m) in the prairies are typified by either Type 1 or Type 2 waters. Table I provides a summary of ion concentrations found in prairie groundwaters along with some beef manure concentrations.

The ions K^+, Cl^-, NO_3-N, and NH_4-N and the element P are generally of low concentrations in prairie groundwaters and of high concentrations in manure. Potassium values generally are below 15 mg/L in all native groundwaters although a few higher values have been reported. Fortin et al. (1991) report some K^+ values at 26 mg/L. Chloride levels are under 50 mg/L in most till materials although it may reach 200 mg/L in some waters of Types 1 and 2, and higher than 500 mg/L in Type 3 waters. If Cl^- is high, then this can indicate long flow paths or waters originating from marine shale, in which case the Na concentrations should also be high. For Type 3 waters, the ratios of Ca/Na and Mg/Na will be very low and TDS should be greater than 3000 mg/L (Freeze and Cherry 1979; Rutherford 1966). Chloride and potassium are of high concentrations in beef and hog manure (Bayne 1997). Total dissolved phosphorous should be less than 0.1 mg/L in groundwaters as this ion readily precipitates and is fixed by minerals at very low concentrations. The concentration of NO_3-N should also be less than 1 mg/L in native groundwaters, and generally any concentrations higher than this, indicates contamination by human activity. An exception to this is that of geologic NO_3-N and NH_4-N values reported in oxidized till zones in southern Alberta (Hendry et al. 1984) that are as high as 200 mg/L (as NO_3^- and NH_4^+). Normal prairie cropping practices (tillage, fallowing, and conventional fertilizer use) can result in soil nitrate levels below the root zone being up to 20 to 40 times that existing beneath uncultivated land (Rennie et al. 1976). Ammonium levels in groundwaters should be low, less than 1 mg/L (as NH_4-N) and likely less than 0.05 mg/L (Coote and Hare 1978). Cations such as K^+ and NH_4^+ do not transport rapidly as they become adsorbed on cation exchange sites or fixed within the clay lattice. Phosphorous becomes easily fixed or will precipitate at low concentrations. Nitrate and Cl^- will be readily transported with water flow; however, NO_3-N can become biologically immobilized or undergo denitrification to N_2 gas.

Investigations of groundwater immediately under or adjacent to feedlots have found NO_3^--N to vary from 1 to 140 mg/L, NH_4-N from 0.02 to 64 mg/L, P from 0.02 to 2 mg/L and Cl^- from 79 to 664 mg/L (Terry et al. 1981; Coote and Hare 1978; Bennett 1975; Sommerfeldt et al. 1973; Miekle et al. 1970). Runoff from beef feedlot pens has been reported containing <1 mg/L NO_3-N, 69 mg/L P, 108 mg/L NH_4-N and 11,000 mg/L total dissolved solids (Kreis et al. 1972).

METHODS and MATERIALS

Site descriptions

Five feedlot sites (referred to as Sites #1 through #5) within 100 km from Saskatoon, Saskatchewan were investigated. The feedlots are within the Dark Brown Soil Zone and range in age from 20 to 35 years.

The general climate of these sites may be represented by that of Saskatoon. The total annual precipitation is about 360 mm with about 200 mm occurring during the growing season of May through August. About 90 mm of precipitation occurs as snow during November through March. The annual potential evaporation is 660 mm. Spring melt is the wettest time of the year in terms of runoff and soil moisture recharge. Groundwater recharge for the prairie region is 1 to 4% of annual precipitation for native grasslands whereas for alternate crop-fallow farming, it can reach 7 to 15% (Miller et al. 1981).

General description of feedlots and piezometer installations

All feedlots were reported to be in constant use since their construction. However no records are available as to stocking densities and usage of individual pens.

Site #1 had the pens built about 1965. The pens had a very gradual slope (1 to 2%) to the north. Soil material in the surface 0.5 m of the pen floors was non plastic, consisting of 69% sand and 14% clay. The site is built within an eroded river valley and the topography is a mixture of slopes and materials. Most of the runoff from the feedlot area was focussed towards a collection system and then piped to a dugout located in a pasture about 80 m from the north end of the pens and about 8-9 m lower in elevation. Some amounts of surface runoff from the feedlot area occurred across the field as evidenced by small gullies and lush vegetative growth in the runoff channels. One core was taken in a pen and four piezometers were established around the dugout (within 10 m) ranging in depth from 9.6 to 14.0 m. Three of the piezometers had water within them, but no water was observed in the pen bore hole and one piezometer.

Site #2 was established in the late 1960's. Drainage was north in some pens and to the northeast in the surrounding landscape. Fields to the north and northeast were cropped and had evidence of flooding in some areas and being permanently wet in others. One core was taken in a pen. A total of seven piezometers were installed, one in the road allowance within 10 m of the pen, two within a horse pasture (100 m from the pens), two within weeds of the yard area (100 m of pens) and two in a wheat field (200 m from the pens but within 15 m of a depression and within 40 m of stockpiled solid manure). The total change in elevation from the pens to the furthest piezometers was 6 m. Soil materials of the top one to three meters of this site were of SM (silty sand) to SP (poorly graded sand), not plastic and with 60 to 80% sand contents. A CH (clay of high plasticity) to CL (clay of low plasticity) till underlay this layer. The screen of one piezometer was in the till sublayer, whereas for the other piezometers the top of the screen intersected the upper coarse textured layer.

Site #3 was established in two stages, the south part (3s) during the mid-1960's and the north parts (3n) in the late 1980's. The north part, before construction of the feedlots, had been in crop and fertilized with feedlot manure from the south part. Soil materials in the surface 0.5 m of both pen floors were non plastic (SM/SP) consisting of 63% sand and 14% clay. Underlying this layer, in both parts, were 4 to 6 m of a CI (clay, medium plasticity) to CH soil type, then at deeper levels were some ML (silt, low plasticity) to SM layers. There was a very gradual slope to the west. Four piezometers (9 to 14.5 m deep) were established immediately west (10 to 20 m) of the old pens (3s) and 10 to 20 m east of a dugout. Another four piezometers (2.5 to 4.5 m deep) were located downslope and immediately to the west of the newer pens (3n) along the edge of a field in crop.

Site #4 was established in the late 1960's. A runoff detention pond was constructed in the early 1990's to the south of the pens (about 100 m distant and 2 m lower from the closest pens). Soil material in the surface 0.5 m of the pen floors had a plasticity index of 37% and consisted of 1% sand and 48% clay. A corehole was established in a pen and a series of five piezometers downslope from this corehole were installed. The piezometers were all four to five meters in depth.

Site #5 had its pens established in the 1970's. Surface drainage at this site was from the north to the south with collection in a slough that had been converted into a holding pond with the establishment of an earthen dam in the mid 1980's. The slough drained out to the south. At the time of drilling it was not possible to obtain a core from within the pens. One core was taken within 10 m of a settling pond at the north end of the property, while six piezometers (4.8 to 11.5 m deep) were established about the holding pond and slough at the south end of the property about 300 m from the nearest pens and 600 m from the north piezometer. Soil material in the surface 0.5 m of the pen floors was non plastic (SP/SM) consisting of 68% sand and 12% clay. Soil samples from these piezometers showed an upper layer of SP/SM soil type that was 1.5 m thick at the northern piezometer to more than 5 m thick for the others. Beneath this soil type was a till layer.

Sampling and analytical methods

Coring for samples and installation of piezometers was done by a churn drill, belonging to PFRA (Prairie Farm Rehabilitation Administration), during fall of 1996. The drill rig obtained undisturbed 760 mm diameter cores within 800 mm long brass tubes. The depth of the test holes ranged between 3 and 15 m, depending upon the depth of the watertable. Cores from all test holes were saved for physical and chemical analysis. Test holes within active pens were filled in immediately after obtaining cores. Test holes outside of pens had piezometers installed using slotted PVC pipe with a sand filler, a bentonite seal at the top of the screen, backfill to within 0.5 m of the surface than another bentonite seal at the soil surface. A total of 37 test holes were done, six were backfilled after sampling as they were located in active pens and the remainder (31) had piezometers installed in them.

The cores obtained with the churn drill were kept within their brass retainers until they reached the PFRA Geotechnical laboratory (Regina, SK). Effort was made to keep the cores cool (below 10°C). There was an extended time period between coring and chemical analysis (three to four months) during which time the samples were transported, extracted from the brass tubes, and stored in glass jars. Due to the extended storage period little reliability were given these NO_3-N values. All samples had gravimetric moisture contents determined and their general lithology described. Selected samples had wet bulk density, Atterburg limits, and grain size distribution (clay and silt by hydrometer, sands by sieving) done at the PFRA Geotechnical laboratory.

Core samples of the surface 150 or 300 mm from the pen floors, were sent for chemical analysis. Analysis of ions was made from saturated paste extract that was prepared from core samples that had been air-dried, groud, and sieved to less than 2 mm. The saturated paste extract was measured for pH, EC (electrical conductivity), and dissolved ions; NO_3^-, Cl^- and SO_4^{2-} by liquid ion chromatography, NH_4-N by selective ion electrode, and elements in filtered solution; Ca, K, Mg, Na, P, and C by inductive coupled plasma (ICP). As it was the element phosphorous determined by the ICP method, this is referred to as total dissolved P within this report.

Table II. Saturated paste chemistry of samples from the surface of active feedlot pen surface and at depth.

Parameter	Depth m	pH	EC mS/cm	Na^+ mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	K^+ mg/L	TDP mg/L	Cl^- mg/L	SO_4^{2-} mg/L	NO_3-N mg/L	NH_4-N mg/L
Mean	0.14	7.5	53	3423	805	711	9328	80	12648	3414	10.4	586
sd	0.11	0.2	13	1977	332	414	3718	71	2812	2563	3.6	308
Mean	5.8	7.8	5.8	360	700	335	52	3	124	3183	0.5	1.9
sd	1.5	0.4	3.8	338	541	269	30	3	112	3012	0.4	0.8

EC and ion concentrations are all from saturated pastes and corrected for field moisture conditions.

sd - standard deviation

TDP - total dissolved phosphorous.

Values are the average of five samples from Sites #1 to #4 with two samples taken from Site #3 (3s and 3n). Not all deep samples were analyzed for NH_4-N , this value comes from 3 samples (one from site #2 and two from #3).

Groundwater samples were taken from 30 piezometers on February 19, June 5, and August 12, 1997. One piezometer remained dry throughout the study period and thus sampling was not possible. The sampling was to coincide with winter pre melt (February), spring after melt which usually occurs by the end of March but the ground does not completely thaw to depth until the end of May and after extensive evapotranspiration of summer (August). The day before sampling, water levels were measured and then the piezometers were bailed to three volumes of the piezometer section holding water or to dryness to allow fresh ground water to seep in for sampling during the next day from the top 500 mm of the water in the piezometer. Samples from waterbodies (natural sloughs and/or runoff detention ponds) within and immediately adjacent to the feedlot operation were taken at the same time. All samples were unfiltered. All groundwater samples were stored at less than 4°C and were taken to the lab for analysis within 24 hours, where they were processed for analysis within the next 24 hours. All samples were analyzed for pH, EC, and dissolved ions; NO_3^-, Cl^- and SO_4^- by liquid ion chromatography, NH_4-N by selective ion electrode, and elements in solution; Ca, K, Mg, Na, P (total dissolved P), and C by ICP.

RESULTS and DISCUSSION

Soil-solution chemistry

Four soil-manure samples were taken from the pen floor (Site #5 could not be sampled at the time) so the effects of feedlot manure upon soil solution chemical properties could be determined relative to deeper samples thought to be uncontaminated (Table II). The value of the information in Table II is that of a relative comparison and not that as absolute, as the chemistry is from saturated pastes. The ions K^+, Cl^-, and NH_4-N, and total dissolved P had the greatest difference between shallow and deep samples (Table II) and thus were used as indicator species for the presence of manure. This coincides with information discussed and presented in Table I. Sodium was also of higher concentration in the feedlot floor relative to deep samples. Samples taken from depths of 3 to 8 m beneath the pen floor had concentrations of K^+ varying from 6 to 38 mg/L; Cl^- from 4 to 180 mg/L; NO_3-N from less than 0.1 to 0.5 mg/L; NH_4-N from 0.9 to 1.2 mg/L; and total dissolved P from 0.1 to 5 mg/L. Although NO_3-N can be used as an indicator of manure seepage, the poor storage of the soil samples may have resulted in changes with the nitrate-nitrogen concentrations.

Selection of background groundwater chemistry

To enable a decision as to whether a particular groundwater sample has elevated (above 'background') concentrations of ions caused by manure, it is necessary to decide upon a concentration level that represents background. As 'background' concentrations will vary somewhat due to geological materials, groundwater flowpaths, and the contribution from agricultural sources other than feedlot manure, it is difficult to select a concentration value that definitely indicates the presence of feedlot manure, especially as in this study groundwater samples upstream from the feedlot were not obtained. To overcome this problem, two concentration levels were chosen for each chemical parameter to represent the possibility of the presence of feedlot manure. The Lower Level divided Class A waters (those with background ion concentrations) from Class B waters (those with slightly elevated ion concentrations indicative of human activity - cropping and/or feedlot manure in low concentrations). The Upper Level divided Class B waters from Class C waters (those with higher than normal ion concentrations that could only be due to feedlot manure). The values of these levels are based on other studies (Table I) and the current study (Tables II and III). If the values are between the lower and upper levels then there is possibility of contamination but it is difficult to state as to whether or not the values are due to the presence of low concentrations of feedlot manure or that of normal fertilizer additions to crop fields that were present before the feedlots. From Tables I and II the best indicators for the presence of manure are elevated concentrations of: Na^+, K^+, Cl^-, NO_3-N, NH_4-N, and total dissolved P. Table IV shows the values of the levels for each site along with the number of piezometers in each of the classes; A, B, and C. The rational for the values and levels choosen are as follows:

Nitrate-nitrogen in groundwaters uncontaminanted by agricultural activities is expected to be less than 1 mg/L. Normal prairie cropping practices can result in higher concentrations. For the lack of any supportive data for background levels, the values of 2 mg/L and 20 mg/L are arbitrarily choosen for the two levels. As some of the sample sizes and/or the analytical method was sometimes insufficient to resolve values less than 1 mg/L, 2 mg/L was choosen as the lower value. Thus below 2 mg/L is considered background (Class A) and above 20 mg/L the water is considered to be contaminanted with feedlot manure (Class C). It is recognized that this form of categorization is not an exact method, however barring other methods (e.g., extensive site monitoring before

Table III. Feedlot site groundwater chemistry, as determined from piezometer water samples.

Site	parameter	WL	pH	EC	Na^+	Ca^{2+}	Mg^{2+}	K^+	TDP	Cl^-	SO_4^{2-}	NO_3-N	NH_4-N	n
		m		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	n
1	mean	9.6	7.7	1.3	53	137	79	5.7	1.0	36	299	2.5	0.4	3
1	sd	0.3	0.2	0.1	8	13	7	2.1	0.7	8	55	1.7	0.5	
2	mean	1.8	7.4	3.4	172	338	209	22.9	3.0	505	647	10.6	3.6	7
2	sd	0.3	0.3	1.0	52	81	84	18.5	1.7	403	464	10.3	8.1	
3s	mean	5.2	7.4	4.5	50	648	222	24.0	4.7	630	382	233.4	0.4	4
3s	sd	0.2	0.3	2.1	37	326	118	15.8	2.5	284	249	156.2	0.2	
3n	mean	2.9	8.0	1.8	42	186	79	5.3	0.6	242	113	38.4	0.1	4
3n	sd	0.3	0.3	0.7	26	45	22	0.5	0.5	165	28	37.1	0.0	
4	mean	3.5	7.6	7.3	930	474	590	56.4	11.5	643	3350	9.7	5.7	5
4	sd	0.8	0.2	1.0	139	59	134	44.4	4.6	358	718	13.9	11.3	
5	mean	1.9	7.3	3.0	104	351	113	41.9	3.3	555	133	22.9	0.7	7
5	sd	1.0	0.3	1.1	60	116	65	52.4	1.9	367	46	37.8	1.0	

TDP - Total dissolved phosphorous
sd - standard deviation
n - number of samples

establishment of the feedlot or use of nitrogen isotopes) this is the only method available. Thus results should only be used with caution and with reference to Tables I, II, and actual data from the sites itself.

Ammonia-nitrogen If groundwater was not affected by human activities then NH_4-N should be less than 0.1 mg/L. As the analytical methods used for our study did not resolve below 0.1 mg/L it is suggested that 0.2 mg/L be used for a lower level and 2.0 mg/L be used for the upper level.

Total dissolved phosphorous Analytical methods were unable to resolve below 0.1 mg/L and at times not below 0.5 mg/L. Samples below the lower limit of 0.5 mg/L were considered to be representative of native groundwater; while samples above 5 mg/L were considered to contain feedlot manure seepage.

Sodium, potassium and chloride ions Unless manure was used as a fertilizer it is not expected that there would be high levels of these ions. In addition Na^+ and K^+ would have very low travel rates due to cation exchange of soil minerals. Native groundwater conditions must be accounted for by using the information discussed in Table I and by considering the range of values at any one site. If the K^+ or Cl^- values are high relative to those values in Table I or relative to other groundwater samples at the same site then there is a possibility of contamination from human sources. The lower level will be a value picked for the site plus one standard deviation (using the coefficient of variation from Table I). The upper level will be the picked value plus two standard deviations.

Groundwater conditions

Groundwater chemistry, as obtained from piezometer samples, is summarized in Table III. The rating as to whether the waters from these piezometers are contaminated or not from manure is given in Table IV.

Site #1 had relatively deep water levels, between 9 m and 10 m depth. The waters in these piezometers are relatively low in concentration of ions, likely representing Type 1 groundwaters (Table I) and appear not to be contaminated by feedlot manure as concentrations of Na^+, K^+, and Cl^- were felt to represent background concentrations (Class A). Total dissolved P, NO_3-N, and NH_4-N did have some slightly elevated values that would not be expected in normal groundwater; however these values make it difficult to definitely indicate the presence of manure.

Site #2 had water levels within two to three meters of the ground surface. The EC and sulphate values are perhaps indicative of Type 2 groundwaters. The high concentrations of total dissolved P, Cl^-, NO_3^- strongly indicate that manure has seeped into the groundwater with six of the seven piezometers showing possible contamination by feedlot manure (Class C).

Site #3 south part is the older site at this location and has water levels about 5.3 m beneath the surface. Thus the waters collected in the piezometers (located 9 to 14.5 m deep) likely represented that of a confined layer located 6 to 7 m beneath the surface. The groundwaters had high EC and Ca^{2+} values, but low Na^+ and Mg^{2+} values. These waters could be that of Type 2 groundwaters. Three of the four piezometers showed definite indications of being contaminanted by manure (Class C); extremely high levels of NO_3-N (278 to 341 mg/L), Cl^- (516 to 877 mg/L), and total dissolved P (5.3 to 7.0 mg/L). Potassium was slightly elevated as compared to expected concentrations in Table I and NH_4-N concentrations were low; these low values could be the function of ion exchange and fixation in the clay minerals of the CI/CH layer.

Site #3 north part is the newer feedlot at this location and also had a SP/SM soil type for the surface one to two meters underlain by a CI/CH soil type. The piezometers here were shallow with the bottoms generally within three to five meters of the surface and the water levels at an average 2.9 m below the ground surface. Although a piezometer was not established in the pen at this site, seepage into the hole during drilling was reported at 2 m below the ground surface. Chemical analysis of groundwaters showed high nitrate-nitrogen and chloride levels at three of the four piezometers. As the EC, Na^+, and SO_4^{2-} are indicative of Type 1 waters and not Type 3 waters (Table I) the chloride is likely not natural to the groundwater. Phosphorous and potassium values were low and likely indicative of background concentrations. Two of the piezometers can be considered to be contaminated by manure (Class C) and the other two piezometers have some indications of agricultural contamination (Class B).

Table III. Feedlot site groundwater chemistry, as determined from piezometer water samples.

Site	parameter	WL	pH	EC	Na^+	Ca^{2+}	Mg^{2+}	K^+	TDP	Cl^-	SO_4^{2-}	NO_3-N	NH_4-N	n
		m		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	n
1	mean	9.6	7.7	1.3	53	137	79	5.7	1.0	36	299	2.5	0.4	3
1	sd	0.3	0.2	0.1	8	13	7	2.1	0.7	8	55	1.7	0.5	
2	mean	1.8	7.4	3.4	172	338	209	22.9	3.0	505	647	10.6	3.6	7
2	sd	0.3	0.3	1.0	52	81	84	18.5	1.7	403	464	10.3	8.1	
3s	mean	5.2	7.4	4.5	50	648	222	24.0	4.7	630	382	233.4	0.4	4
3s	sd	0.2	0.3	2.1	37	326	118	15.8	2.5	284	249	156.2	0.2	
3n	mean	2.9	8.0	1.8	42	186	79	5.3	0.6	242	113	38.4	0.1	4
3n	sd	0.3	0.3	0.7	26	45	22	0.5	0.5	165	28	37.1	0.0	
4	mean	3.5	7.6	7.3	930	474	590	56.4	11.5	643	3350	9.7	5.7	5
4	sd	0.8	0.2	1.0	139	59	134	44.4	4.6	358	718	13.9	11.3	
5	mean	1.9	7.3	3.0	104	351	113	41.9	3.3	555	133	22.9	0.7	7
5	sd	1.0	0.3	1.1	60	116	65	52.4	1.9	367	46	37.8	1.0	

TDP - Total dissolved phosphorous
sd - standard deviation
n - number of samples

establishment of the feedlot or use of nitrogen isotopes) this is the only method available. Thus results should only be used with caution and with reference to Tables I, II, and actual data from the sites itself.

Ammonia-nitrogen If groundwater was not affected by human activities then NH_4-N should be less than 0.1 mg/L. As the analytical methods used for our study did not resolve below 0.1 mg/L it is suggested that 0.2 mg/L be used for a lower level and 2.0 mg/L be used for the upper level.

Total dissolved phosphorous Analytical methods were unable to resolve below 0.1 mg/L and at times not below 0.5 mg/L. Samples below the lower limit of 0.5 mg/L were considered to be representative of native groundwater; while samples above 5 mg/L were considered to contain feedlot manure seepage.

Sodium, potassium and chloride ions Unless manure was used as a fertilizer it is not expected that there would be high levels of these ions. In addition Na^+ and K^+ would have very low travel rates due to cation exchange of soil minerals. Native groundwater conditions must be accounted for by using the information discussed in Table I and by considering the range of values at any one site. If the K^+ or Cl^- values are high relative to those values in Table I or relative to other groundwater samples at the same site then there is a possibility of contamination from human sources. The lower level will be a value picked for the site plus one standard deviation (using the coefficient of variation from Table I). The upper level will be the picked value plus two standard deviations.

Groundwater conditions

Groundwater chemistry, as obtained from piezometer samples, is summarized in Table III. The rating as to whether the waters from these piezometers are contaminated or not from manure is given in Table IV.

Site #1 had relatively deep water levels, between 9 m and 10 m depth. The waters in these piezometers are relatively low in concentration of ions, likely representing Type 1 groundwaters (Table I) and appear not to be contaminated by feedlot manure as concentrations of Na^+, K^+, and Cl^- were felt to represent background concentrations (Class A). Total dissolved P, NO_3-N, and NH_4-N did have some slightly elevated values that would not be expected in normal groundwater; however these values make it difficult to definitely indicate the presence of manure.

Site #2 had water levels within two to three meters of the ground surface. The EC and sulphate values are perhaps indicative of Type 2 groundwaters. The high concentrations of total dissolved P, Cl^-, NO_3^- strongly indicate that manure has seeped into the groundwater with six of the seven piezometers showing possible contamination by feedlot manure (Class C).

Site #3 south part is the older site at this location and has water levels about 5.3 m beneath the surface. Thus the waters collected in the piezometers (located 9 to 14.5 m deep) likely represented that of a confined layer located 6 to 7 m beneath the surface. The groundwaters had high EC and Ca^{2+} values, but low Na^+ and Mg^{2+} values. These waters could be that of Type 2 groundwaters. Three of the four piezometers showed definite indications of being contaminanted by manure (Class C); extremely high levels of NO_3-N (278 to 341 mg/L), Cl^- (516 to 877 mg/L), and total dissolved P (5.3 to 7.0 mg/L). Potassium was slightly elevated as compared to expected concentrations in Table I and NH_4-N concentrations were low; these low values could be the function of ion exchange and fixation in the clay minerals of the CI/CH layer.

Site #3 north part is the newer feedlot at this location and also had a SP/SM soil type for the surface one to two meters underlain by a CI/CH soil type. The piezometers here were shallow with the bottoms generally within three to five meters of the surface and the water levels at an average 2.9 m below the ground surface. Although a piezometer was not established in the pen at this site, seepage into the hole during drilling was reported at 2 m below the ground surface. Chemical analysis of groundwaters showed high nitrate-nitrogen and chloride levels at three of the four piezometers. As the EC, Na^+, and SO_4^{2-} are indicative of Type 1 waters and not Type 3 waters (Table I) the chloride is likely not natural to the groundwater. Phosphorous and potassium values were low and likely indicative of background concentrations. Two of the piezometers can be considered to be contaminated by manure (Class C) and the other two piezometers have some indications of agricultural contamination (Class B).

Table IV. Number of piezometers at each site with ion concentrations indicative of no presence of agricultural contaminations; possible presence; and definite presence of feedlot manure.

Site	Class[†]	Summary	Na^+ mg/L	K^+ mg/L	TDP mg/L	Cl^- mg/L	NO_3-N mg/L	NH_4-N mg/L
1	A	/ 2	<91 / 3	<7 / 3	<0.5 / 0	<60 / 3	<2 / 2	<0.2 / 2
1	B	/ 1	91 / 0	7 / 0	0.5 / 3	60 / 0	2 / 1	0.2 / 1
1	C	/ 0	129 / 0	10 / 0	5.0 / 0	95 / 0	20 / 0	2.0 / 0
2	A	/ 0	<220 / 5	<16 / 4	<0.5 / 0	<92 / 1	<2 / 2	<0.2 / 1
2	B	/ 1	220 / 2	16 / 1	0.5 / 5	92 / 0	2 / 3	0.2 / 5
2	C	/ 6	330 / 0	25 / 2	5.0 / 2	140 / 6	20 / 2	2.0 / 1
3s	A	/ 0	<50 / 3	<33 / 3	<0.5 / 1	<585 / 2	<2 / 0	<0.2 / 1
3s	B	/ 1	50 / 0	33 / 1	0.5 / 0	585 / 2	2 / 1	0.2 / 3
3s	C	/ 3	75 / 1	49 / 0	5.0 / 3	890 / 0	20 / 3	2.0 / 0
3n	A	/ 0	<33 / 2	<9 / 4	<0.5 / 2	<237 / 2	<2 / 0	<0.2 / 2
3n	B	/ 2	33 / 0	9 / 0	0.5 / 2	237 / 1	2 / 2	0.2 / 0
3n	C	/ 2	46 / 2	13 / 0	5.0 / 0	371 / 1	20 / 2	2.0 / 0
4	A	/ 0	<1160 / 5	<37 / 3	<0.5 / 0	<642 / 3	<2 / 0	<0.2 / 0
4	B	/ 2	1160 / 0	37 / 0	0.5 / 1	642 / 1	2 / 4	0.2 / 4
4	C	/ 3	1595 / 0	52 / 2	5.0 / 4	910 / 1	20 / 1	2.0 / 1
5	A	/ 0	<36 / 2	<9 / 2	<0.5 / 0	<223 / 2	<2 / 5	<0.2 / 2
5	B	/ 3	36 / 0	9 / 1	0.5 / 6	223 / 0	2 / 0	0.2 / 2
5	C	/ 4	51 / 5	13 / 4	5.0 / 1	349 / 5	20 / 2	2.0 / 1

[†] For explanation of the Classes please see text.

The 'slash' separates the concentration values from the number of piezometers within the Class. For example: Site 5 under Na^+ column: 'A' / 2 indicates that there were 2 piezometers with concentrations less than 36 mg/L; B 36 / 0 indicates that there were 0 piezometers of concentrations between 36 and 51 mg/L; and C 51 / 5 means there were 5 piezometers with concentrations greater than 51 mg/L

Site #4 had piezometers installed between four and five meters deep in lacustrine materials of high clay content (48%) and of a CH soil type. The water level ranged between 3.2 and 4.4 meters in depth. The screens were in the bottom 2 m of the piezometer holes. One piezometer had a high NO_3-N level (34 mg/L) and another had a high NH_4-N concentration (26 mg/L). The high concentrations of Cl^-, K^+, as well as most of the other ions, could be due to groundwater conditions representative of Type 3 waters (high in Na^+, Cl, and SO_4^{2-} but low in Ca^{2+} relative to Na^+) in contact with marine shale (Rutherford 1966). This site also had the highest TDP concentrations as compared to other sites (Table III). This site is more difficult to categorize, but if the classification was limited to that of TDP and the nitrogen ions then three piezometers indicate contamination by manure (Class C).

Site #5 groundwater levels ranged from 0.5 m for the northern piezometer to 1.5 to 3.8 m for the southern piezometers. Although the EC, Na^+, Ca^{2+}, and Mg^{2+} are indicative of Type 2 groundwaters the SO_4^{2-} is very low, more similar to Type 1 waters. The northern piezometer had very high levels of Cl^- (1165 mg/L), K^+ (100 mg/L), and total dissolved P (6.5 mg/L), whereas NO_3-N was less than 3 mg/L. The other six southern piezometers had high levels of NO_3-N (318 and 354 mg/L) for two piezometers, whereas the other four had high Cl^- levels (between 500 and 600 mg/L) and high total dissolved P levels (2.5 to 4.1 mg/L). One piezometer had a high NH_4-N level (2.4 mg/L). Four of the seven piezometers here showed a definite possibility of manure seepage (Class C), while the other three showed some indication of contamination by human activities (Class B).

Of the 30 piezometers only two had concentrations which could definitely be considered as not being affected by any human agricultural activity; ten piezometers showed some evidence of perhaps being affected; and 18 had ion concentrations such that they could only have come from high amounts of feedlot manure seeping to depth. Considering that most of these feedlots are at least 25 years old and that the groundwater was shallow in most instances (22 piezometers had groundwater levels less than 4 m in depth) it is not surprising that there is such a high degree of manure seepage. Today's siting regulations for feedlots would not have allowed the location of some of these feedlots.

SUMMARY and CONCLUSIONS

The current study completed a drilling program and installation of piezometers in five cattle feedlots about central Saskatchewan to characterize groundwater about the feedlots as to the presence of manure. Water samples were collected from 30 piezometers installed at five feedlots. Four feedlots were constructed in the 1960's, one in the 1970's, and part of one of the feedlots was constructed in the 1980's. All the feedlots have been in continuous use since their construction date.

Samples from the feedlot floor, as compared to deeper soil samples, indicated that the following solutes could be used to indicate the presence of manure in groundwaters; Na^+, K^+, total dissolved P, Cl^-, NO_3-N, and NH_4-N. Based upon the indicator ions, consideration of 'background' levels of these ions found in natural groundwaters and groundwaters possibily contaminanted by normal prairie cropping practices, as opposed to feedlot manure seepage, it is concluded that four of the five different feedlots show evidence of groundwater contamination from feedlot manure. Of the 30 piezometers only two showed no evidence of any contamination, 10 showed evidence of some contamination, and 18 had high concentrations of more than one of these indicator ions that could only be explained by seepage from feedlot manure. The groundwater levels at a number of these feelots were quite shallow (Sites 2, 3n, 4, and 5 were all less than 4 m depth); such siting of feedlots would likely not be accepted within todays regulations.

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