EFFECTS OF BEDDING TYPE AND WITHIN-PEN LOCATION ON FEEDLOT RUNOFF

E. C. S. Olson, D. S. Chanasyk, J. J. Miller

ABSTRACT. *This two-year study examined the effects of two types of bedding materials (straw and wood chips) and two within-pen locations (bedding pack and pen floor) on various feedlot runoff parameters in southern Alberta, Canada, using a rainfall simulator. Bedding type affected antecedent factors and hydrological parameters differently by year. Bedding pack locations absorbed 23.5% to 32.9% more moisture, had about 8 cm greater manure depths, slopes between 2.1% and 5.1% steeper, and surfaces that were 2.6% to 5.7% rougher than pen floor locations. Pen floor locations had clod bulk densities that were 0.83 Mg m^{-3} greater than bedding pack locations in 1998. However, the effect of bedding packs on these properties depended on the amount of bedding added, which depended on feedlot conditions. Runoff began sooner from pen floor than from bedding pack locations. Once runoff started, the amount and type of bedding material, length of time since fresh bedding was added, and within-pen location affected the time for specific runoff volumes. For example, in 1998, 6 L of runoff were collected about 3 min faster from wood chips than from straw bedding and about 7 min faster from the pen floor than from the bedding pack. Runoff coefficients increased during the simulation events and occasionally exceeded rainfall application rate depending on whether or not water in depression storage was released. Treatment effects were dependent on year of study, and were inconsistent. Thus, further study is warranted regarding the effects of bedding type on feedlot runoff.*

Keywords. *Antecedent conditions, Confined feeding operation, Hydrologic response, Initial abstraction.*

Beef cattle feedlots are usually constructed by removing the topsoil and landscaping the exposed mineral subsoil to form a smooth, sloped surface to drain water (Kennedy et al., 1999) and then divided into fenced pens. Feedlot pens are often bedded to provide cattle comfort, especially in a cold or wet climate. When pens are bedded, two distinct areas develop: the bedded area, and the unbedded pen floor area. The bedded area is located away from the drinking source and feed bunk. Between the bedded area and the unbedded pen floor is a transitional area where the cattle disperse the bedding material. It is reasonable to suppose that the type of material used for animal bedding will influence the ability of the bedded area to absorb precipitation, and this will consequentially affect the amount of runoff. Thus, in comparing pen floor areas to bedded areas, the type of bedding must be taken into consideration. Barley or wheat straw traditionally has been the source of bedding for feedlot cattle, but wood products such as sawdust, post peelings, and bark may be equally viable sources of bedding (McAllister et al., 1998).

Submitted for review in January 2005 as manuscript number SW 5699; approved for publication by the Soil & Water Division of ASABE in July 2006.

LRC Contribution No. 38704069.

The authors are **Edith C. S. Olson,** Former Graduate Student, and **David S. Chanasyk, ASABE Member Engineer,** Professor, Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada; and **Jim J. Miller,** Research Scientist, Agriculture and Agri-Food Canada, Lethbridge, Alberta, Canada. **Corresponding author:** David S. Chanasyk, Department of Renewable Resources, University of Alberta, Edmonton, AB, Canada T6G 2H1; phone: 780-492-6538; fax: 780-492-4323; e-mail: david.chanasyk@ualberta.ca.

During periods when feedlots are stocked, layers develop within pen floors. Watts and McKay (1986), working on Australian feedlots, conceptualized the upper portion of a feedlot as a layer of manure, which acts like a sponge, on top of an impermeable compacted layer of mixed organic and mineral soil. The compacted layer is dense, charcoal black in color, and inhibits percolation. Under the compacted layer is a gleyed layer of mineral soil, beneath which is a hardpan layer. The presence of a compacted layer and its effect on percolation also affects feedlot runoff through the impediment of the downward movement of water.

MacAlpine et al. (1996), using large (outside diameter = 0.74 m) double-ring infiltrometers, measured substantial differences in infiltration rates on a newly constructed pen with no manure and no compacted layer and on a three-year-old pen with intact manure and compacted layers. The three-year-old pen had the lowest initial infiltration rate. During week-long tests, infiltration was zero once the manure layer above the compacted layer became saturated. Although one test reached zero infiltration in 30 min, the average time was 8 days. Infiltration in the newly constructed pen, without the presence of the compacted layer, continued as long as there was a supply of water. Mielke and Mazurak (1976) removed undisturbed soil cores containing the compacted layer and the mineral soil layer beneath and determined that the saturated hydraulic conductivity of the mineral soil layer was 28 times that of the compacted layer.

Slope is an important factor that governs runoff from feedlot pens (Gilbertson et al., 1980), and slopes between 2% and 6% are adequate to drain water from feedlot pens (McNeil and Sawyer, 1998). Other main factors that influence runoff from pens are the depth of the manure pack (Clark et al., 1975; Watts and McKay, 1986), antecedent moisture conditions of the manure pack (Miner et al., 1966;

Gilbertson et al., 1980), and pen surface roughness (MacAlpine et al., 1996).

The depth and antecedent moisture content of the manure pack affect the amount of water that the manure pack can absorb before runoff begins. The depth of water that a soil can absorb before runoff begins is called the initial abstraction (Ponce, 1989). Feedlot runoff studies have shown varying initial abstractions. Kennedy et al. (1999) reported initial abstractions up to 25 mm in a semi-arid region of the North American Great Plains near Vegreville in east-central Alberta. In the southern Great Plains near Bushland, Texas, Clark et al. (1975) found that, in general, about one-third of the rainfall up to 70 mm became runoff when the total rainfall exceeded 10 mm. Gilbertson et al. (1980), in a summary of feedlot-runoff control in the U.S., stated that the first centimeter of rainfall was retained on the feedlot surface. Antecedent moisture conditions undoubtedly play a key role in determining initial abstraction.

Once the surface has become wet, cattle moving around the pens create depressions that can retain precipitation on the feedlot surface. Whereas precipitation can run off smooth feedlot pen surfaces, depressions in wet feedlot surfaces increase pen surface roughness and increase surface storage in wet feedlots compared to dry feedlots. Clark et al. (1975) determined that a wet, thick manure pack tends to store water, likely due to the increase in depressional storage. Lott et al. (1994), on feedlots in Australia, found that rough feedlot pen surfaces stored up to 11.6 mm of rainfall before runoff began, whereas smooth surfaces stored up to 5.7 mm of rain. Runoff begins only when the manure is saturated and the surface depressions have been filled (Miner et al., 1966).

There is a growing interest by producers in the use of wood chips mixed with sawdust as bedding material in comparison to the traditional cereal straw, but there is a lack of information on the effect of this bedding type on the quantity and quality of runoff. Although there is some literature on the water retention properties of straw and wood chips alone (Schofield, 1988; Miller et al., 2000), information on the comparison of the hydrologic response of cattle pens that are bedded with either straw or wood chips is lacking. The separate contributions of the bedded area and the pen floor to feedlot hydrology also require further study.

This study had three objectives: (1) to evaluate the impact of two types of bedding materials on antecedent soil conditions prior to rainfall simulation, (2) to compare the hydrological response of these two bedding types and within-pen locations, and (3) to determine the most significant factors affecting runoff from the two bedding types and locations.

Materials and Methods

Site Selection

The 1.2 ha research feedlot at the Agriculture and Agri-Food Canada Research Centre at Lethbridge, Alberta, was used for the study. The feedlot layout is shown in figure 1. Each of the 32 pens in the feedlot measured 14 × 19.5 m. The feedlot capacity at the time of the study was approximately 500 head of beef cattle, with 15 cattle per pen, for a stocking density of 18 m^2 $head^{-1}$, which is a stocking density comparable to that of commercial feedlots. For example, Kennedy et al. (1999) reported a stocking density

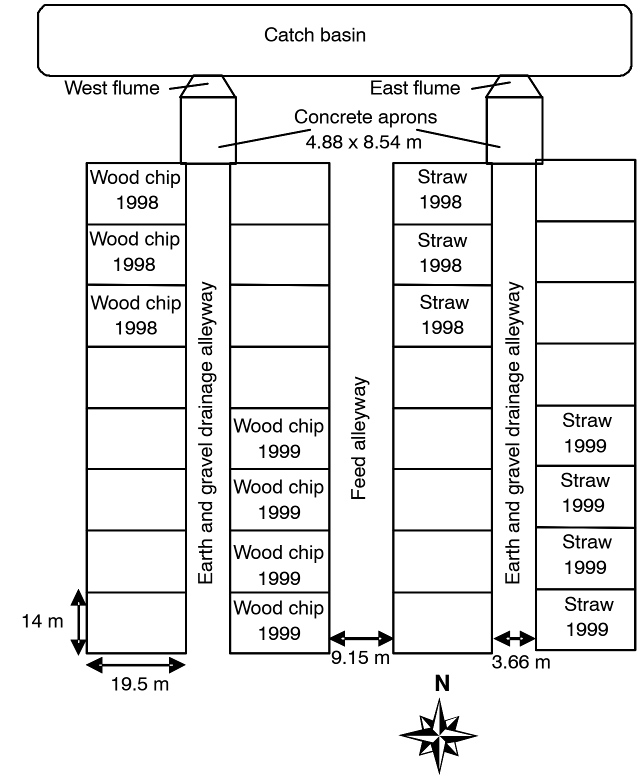

Figure 1. Feedlot layout.

of 17.25 m^2 $head^{-1}$ for a commercial 25,000 head feedlot in east-central Alberta. The cattle in our study were all steers weighing approximately 300 kg each and were placed in the pens on 24 November 1997. They over-wintered in the feedlot and were removed by 2 July 1998, at which time they weighed approximately 580 kg each. The pens were cleaned within two weeks of the cattle leaving. This cleaning took place in July 1998, after data collection for this study had been completed for that year. The pens were restocked on 7 December 1998 with steers weighing approximately 300 kg each. Rainfall simulations were conducted in the active (stocked) pens during the intervals of 2 June to 23 July 1998 and 13 May to 15 June 1999 before these cattle were removed on 17 June 1999, at which time they weighed approximately 565 kg each.

Prior to the start of the simulations in 1998, 188.4 mm of precipitation had been received since 1 January. An additional 192.4 mm of precipitation was received between 2 June and 23 July 1998. In 1999, the site received 75.9 mm of precipitation from 1 January to the start of the rainfall simulations and an additional 92 mm between 13 May and 15 June. There was 127% more precipitation from 1 January to the conclusion of the runoff studies in 1998 than in 1999. Six storm events in 1998 and two in 1999 produced natural runoff from the feedlot, and this runoff was diverted into a catch basin capable of holding 4,439 m^3.

Fresh bedding was added to the pens whenever the feedlot manager considered it warranted based on the amount of tag (mud, bedding, or manure) on the animals and the conditions of the bedding area. In wet weather, the feedlot manager would have made more frequent additions of straw bedding to pens than wood chips, as straw bedding stays wetter than wood chip bedding. Generally, the same amount of straw or

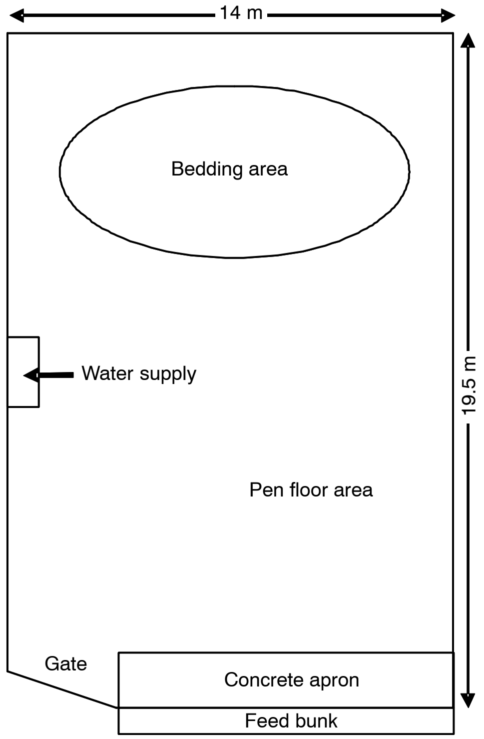

Figure 2. Layout of feedlot pen. Pen dimensions are drawn to scale.

wood chip bedding was added to each pen on the same date. The mean total mass of straw added per pen was 4,332 kg in 1998 (20 applications) and 3,786 kg in 1999 (16 applications). The mean total mass of wood chips added per pen was 13,783 kg in 1998 (14 applications) and 7,035 kg in 1999 (7 applications).

The bedding material was added using a tractor with a front-end loader. The bedding material was deposited on the bedding area of the pen (fig. 2) and then dispersed by the cattle activity. This procedure is similar to those used by commercial feedlots. The wood chip bedding was a mixture of sawdust and bark peelings derived from approximately 80% lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and 20% white spruce (*Picea glauca* (Moench) Voss) and was provided by Sunpine Forest Products, Sundre, Alberta.

Of the 32 cattle pens within the feedlot, three pens bedded with barley straw and three pens bedded with wood chips were selected in 1998 (fig. 1). That year, two sites each on the bedding and pen floor areas of each pen were selected for rainfall simulation. In 1999, four pens bedded with wood chips and four with straw were selected (fig. 1). In 1999, rainfall simulations were conducted on one site on the bedding and pen floor locations of each pen (fig. 2). The bedding area was visually distinct from the pen floor area as a mound located towards the drainage alleyway side of the pens (fig. 2). The mound became less prominent once the cattle had dispersed the bedding, especially when conditions in the feedlot remained dry for extended periods of time and the bedding became pulverized by the cattle hooves and mixed with the manure throughout the pen. However, the location of the bedding area could always be determined as a raised mound within the pen.

The bedding area locations selected for the rainfall simulations were randomly selected on the edges of the mounded bedding areas where they sloped towards the pen floor. Bedding area sites that sloped towards the drainage alleyways were not selected, as such sites did not have access for the equipment required for the simulation. The pen floor sites were randomly selected within an area that excluded overlap from the cattle's water supply, feed trough, and bedding area. This area was selected as being visually representative of the pen floor conditions.

Generation and Collection of Simulated Runoff

Rainfall simulations, using the portable Guelph Rainfall Simulator II (fig. 3) (Tossell et al., 1987), were conducted at two sites within each pen on the bedding area and at two sites within each pen on the pen floor in 1998 (fig. 2). The Guelph Rainfall Simulator II (GRS II) provided simulated rainfall at the rate of 54 mm h^{-1} on a 1.0 × 1.0 m area of each site to generate runoff. This was achieved by using a 9.5 mm diameter nozzle at a pressure of 97 kPa at a height of 1.0 m above the pen surface. For the Lethbridge region, a rate of 54 mm h^{-1} for 20 min represents a return period of 5 years. The GRS II achieves in excess of 90% uniformity of coverage, but does not generate the velocity of actual rainfall due to the height limitation (Tossell et al., 1987). Demineralized water from Agriculture and Agri-Food Canada Lethbridge Research Centre was used to supply the simulator. The water tank was filled at least one day prior to a rainfall simulation, and the inside of the tank was regularly checked for cleanliness.

A stainless steel frame formed the border of the 1.0 m square on three sides. A triangular metal apron formed the fourth side. The apex of the metal triangle was open to allow runoff to pass over it and into 1.0 L collection jugs. The metal apron was protected from the spray of the GRS II by a Plexiglas cover. Rain falling onto the Plexiglas cover was directed to a plastic tube and diverted away from the runoff collection point. The border of the metal frame was sealed around the outside by granular bentonite clay, and a hole dug under the apex allowed for the placement of the runoff collection containers. The rainfall simulator was protected from wind by a portable, fine-mesh windscreen, which could be quickly erected and taken down at each site. Nineteen consecutive runoff samples of approximately 700 mL each were collected in the containers during each runoff event, and the volume of each sample was measured.

The times from the start of the simulation to initial ponding of the site (visually assessed), to full ponding of the site (visually assessed), to start of runoff, and the times required to collect each sample were recorded with a stopwatch. Initial ponding was deemed to occur when ponding was first observed, while full ponding was identified when depressional storage appeared to be full but runoff had not yet commenced. The runoff phase commenced when water started to fill the first collection container. After 19 runoff samples had been collected, the GRS II was shut down. The total time to generate runoff and collect samples varied from 20 to 60 min, while the time to collect 19 samples varied from 14 to 41 min.

Measurement of Antecedent Conditions

The gravimetric moisture content of the pen soil, the pen surface roughness, the slope of the site, and the depth of the manure area were measured just prior to rainfall simulations. The gravimetric moisture samples were taken from the surface manure layer, and moisture was reported on a

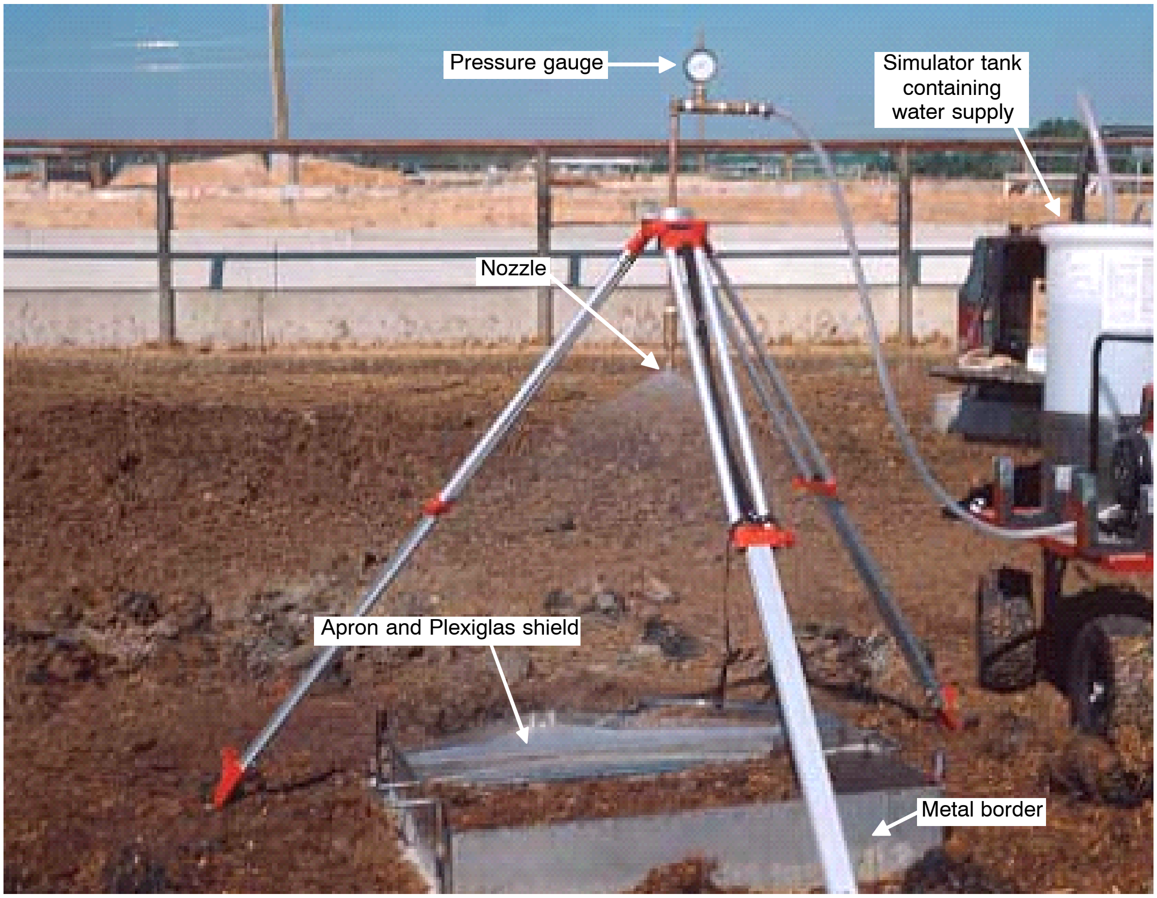

Figure 3. Guelph Rainfall Simulator II.

dry-weight basis. Data were collected by compositing three samples from the 0 to 3 cm depth increment taken from around the rainfall simulation site. The samples were transferred to aluminum foil trays, weighed, oven dried at 60°C (standard for drying organic samples such as manure) to a constant weight, and then re-weighed. Volumetric moisture contents were calculated from gravimetric moisture contents using bulk densities determined with the core method. Pen surface roughness measurements were taken just prior to rainfall simulations using the chain method (Saleh, 1993). Three surface roughness measurements were taken across the slope of the simulated rainfall site within the confines of the metal border and averaged for each site. The slope at each runoff measurement location was measured using a level, 1.0 m in length (run), placed so that one end was on the pen surface within the area to which rainfall would be applied. The level was held so that the bubble indicated when it was horizontal. The vertical distance from the pen surface to the other end of the level was measured (rise), and the percent slope was calculated as the rise over run multiplied by 100.

Random samples of manure clods were selected from around the rainfall simulation site. The actual number and size of clods varied from site to site, but enough samples were taken to be representative of clods at the site. The clod samples were stored in a cooler at 4°C until their gravimetric moisture contents and densities were determined. Clod density was determined using the paraffin wax method (Blake, 1965).

Close to each simulated rainfall site, a hole was dug through the manure layer to the compacted layer for pen floor sites and through the manure and bedding material mixture for bedding sites. Samples of the compacted layer were collected using 3.0 cm high × 5.4 cm diameter cores. Metal rings were carefully pushed into the compacted layer for that purpose. Cores were stored in metal moisture cans until analyzed. The cores were weighed, oven dried to a constant weight at 105°C, and then re-weighed for determination of moisture content and bulk density. The depth of the manure was measured in the same hole using a ruler.

Data Analyses

The same factors were measured both years, using the same methods and procedures. The relationships between bedding type, location, and hydrological response were examined separately for each year of the study. Data for each year were analyzed for significant differences in antecedent conditions and hydrological response between bedding types (straw and wood chips) and between within-pen locations (pen floor and bedding area). Analyzing the data by year allowed for consideration that different pens and different numbers of sites within each pen were used in each year.

Straw and wood chips were designated as treatments and bedding area and pen floor as locations in the statistical analyses. The measurements for clod bulk density, manure depth, surface moisture, compacted layer moisture and bulk density, surface roughness, and slope were averaged for each simulated runoff location within a given pen. Analysis of variance (ANOVA) was calculated for each of these factors using the General Linear Model (GLM) in SAS (1989). The level of significance (alpha) was set at 0.05, and data were tested for normality using the Proc Normal command in SAS. A test for homogeneity of variance was not performed because the small number of samples in the data sets rendered such a test meaningless. Least-square means were used to determine whether there were significant differences between the interaction of bedding type and location.

Initial abstraction was calculated for each location by multiplying the time in seconds until initial runoff by the depth of water applied per second and analyzed using an ANOVA. Graphs of cumulative volume against cumulative time were drawn for each location, and the time required to collect 0, 2, 4, 6, 8, 10, and 12 L of runoff was interpolated from them and used in the ANOVA. The average runoff rate [depth of runoff collected (mm) divided by time elapsed from start of runoff collection to when the container was removed (h)] was plotted for each location against elapsed time since the start of the simulation. The average runoff rates (mm h^{-1}) and runoff coefficients since runoff initiation when 2, 4, 6, 8, 10, and 12 L of runoff had been collected were tabulated, and an ANOVA with $\alpha = 0.05$ was used to indicate significant differences. Runoff coefficients were calculated as the depth of runoff collected when a specified volume of runoff had been collected (2, 4, 6, 8, 10, or 12 L) divided by the depth of simulated rainfall that had been applied from the start of the simulation to generate that volume of runoff.

Stepwise regression was used to determine the variables that significantly influenced the time to start of runoff, using $\alpha = 0.15$. The variables used in the stepwise regression model were moisture content of the compacted layer, bulk density of the compacted layer, pen surface moisture content, clod density, depth of manure, pen surface slope, and pen surface roughness.

Results and Discussion

Antecedent Conditions

Bedding type had a significant effect on pen surface gravimetric moisture and clod bulk density in 1998 and a significant effect on slope and pen surface roughness in 1999 (table 1). Location within the pen significantly affected the compacted layer bulk density and the clod bulk density in 1998 and the pen surface gravimetric moisture, manure depth, slope, and pen surface roughness in both years of the study. The bedding type and location combination had a significant effect on clod bulk density in 1998, on pen surface gravimetric moisture and slope in 1999, and on pen surface roughness in both years of the study.

Pens bedded with straw had a lower average compacted layer gravimetric moisture content and higher average compacted layer bulk density for both years than pens bedded with wood chips (table 1). Bedding pack locations in the pen had significantly ($P \leq 0.05$) higher pen surface gravimetric moisture content, manure depth, slope, and pen surface roughness than pen floor locations. In 1998, bedding pack had significantly lower clod densities than pen floor; however, during the 1999 season, the average densities were non-significantly lower.

Significantly higher pen surface gravimetric moisture in wood chip pens than in straw pens in 1998 was likely due to the greater weights of wood chip bedding than straw bedding added to the pens in 1998 than in 1999. In a 120-day experiment during 1998 at the same feedlot used for this study, McAllister et al. (1998) determined that cattle were bedded 1.4 times more often with straw than with wood chips. Therefore, it is likely that the straw-bedded pens used in our study were also bedded more frequently than pens bedded with wood chips. McAllister et al. (1998) also reported that the greater wood chip density resulted in 13.7 Mg wood chips per pen being added to pens, compared with only 4.3 Mg barley straw per pen. However, much of the wood chip mass was moisture. The bedding material gravimetric moisture

Table 1. Means of antecedent conditions for feedlot-pen component runoff.[a]

		Bedding Type		Location	
Parameter	Year (*n* =)	Straw	Wood chips	Bedding pack	Pen floor
Compacted layer gravimetric moisture (% d.b.)	1998 (24)	20.4	20.7	16.2	21.9
	1999 (16)	17.9	29.2	27.8	19.3
Compacted layer volumetric moisture (%)	1998 (24)	33.1	32.1	28.7	30.7
	1999 (16)	28.5	40.6	40.0	29.5
Compacted layer bulk density (Mg m^{-3})	1998 (24)	1.62	1.55	1.77 a	1.40 b
	1999 (16)	1.59	1.39	1.44	1.53
Pen surface gravimetric moisture (% d.b.)	1998 (24)	32.1 b	42.8 a	53.9 a	21.0 b
	1999 (16)	31.5 b	28.0	41.5 a	18.0 b
Clod bulk density (Mg m^{-3})	1998 [b]	0.68	0.97 a	0.41 b	1.24 a
	1999 (8)	0.46	0.41	0.34	0.52
Pen surface volumetric moisture (%)	1998 (24)	21.8	41.5	22.1	26.0
	1999 (16)	14.5	11.5	14.1	9.4
Manure depth (cm)	1998 (36)	9.1	10.1	13.9 a	5.3 b
	1999 (32)	13.6	12.9	17.6 a	9.5 b
Slope (%)	1998 (24)	4.4	4.7	5.6 a	3.5 b
	1999 (24)	6.6 a	4.2 b	7.4 ba	2.3 b
Pen surface roughness (%)	1998 (72)	11.3	12.2	14.6 a	8.9b
	1999 (48)	11.5 a	8.8 b	11.5 a	8.9 b

[a] Means between years for each bedding type and location combination that are not followed by letters are not significantly different ($P \leq 0.05$).
[b] (12 straw, 11 wood chips).

content prior to being added to the pen was 45.5% for wood chips, compared to 12.1% moisture content for barley straw (McAllister et al., 1998). When dry weights are considered, 1.9 times more wood chips (by mass) were used compared to straw in 1998 (McAllister et al., 1998).

The wood chip bedding used was mainly a mixture of lodgepole pine sawdust and bark peelings. Allison and Anderson (1951) stated that fine pine sawdust absorbed 5.45 kg of water per kg of sawdust, and pine shavings absorbed 2.57 kg of water per kg of shavings. The percentage of sawdust present in the wood chip bedding material would therefore affect absorption, with greater percentages of sawdust increasing the absorption capacity. Miller et al. (2000), using the same wood chip and straw beddings as used in this study, determined that on a gravimetric basis, wood chips absorbed significantly more water than straw after wetting for 27 h.

The significant difference in clod bulk density between wood chips and straw bedding in 1998 was likely due to the greater density of wood chips compared to straw and the compaction of the pen surface by the cattle. Miller et al. (2000) determined that the bulk density of the wood chip bedding materials used in this study (0.13 Mg m^{-3}) was significantly different from that of the straw (0.02 Mg m^{-3}). The surface clod bulk densities taken from the wood chip and straw-bedded pens were greater than the values of the wood chips and straw alone. These density differences were likely due to clods being a mixture of bedding material, soil, and manure that has been compacted by the action of cattle moving in the pens.

Significant differences in slope between bedding types in 1999 were likely the result of higher mounds of straw bedding than wood chip bedding. Straw bedding was in the form of bales when first added to pens. These bales elevated the bedding pack location higher than did wood chip bedding, which was in the form of loose material. Differences in slope between bedding types persisted for some time after the addition of fresh bedding. The significant differences in roughness between bedding materials in 1999 was likely due to cattle being able to pack down the loose wood chip bedding more easily than straw bedding.

Location had more effect on antecedent conditions than did bedding type. A significant difference between locations for pen surface gravimetric moisture was expected. Bedding material in the bedding pack locations should absorb more moisture than unbedded pen floors. Deeper manure in bedded locations would also absorb more moisture than the thinner manure layer of the pen floors. These factors contributed to greater absorption properties of bedded locations. The significantly greater slopes of bedded locations were due to the presence of the mounded bedding material. Bedding materials also impart roughness to bedded locations not found in unbedded pen floors. Pen surface clod bulk densities were significantly different for location, likely due to bedding pack materials mixed with manure to form clods in bedding pack locations and soil mixed with manure to form clods in pen floor locations. Soil has a higher bulk density than manure, straw, and wood chips, so the presence of the soil in a clod would impart a greater bulk density to the clod.

There was a significant interaction between bedding type and location for pen surface clod density in 1998. Clod bulk densities for pen floor locations of wood chip bedded pens were highest, likely due to greater additions of wood chip bedding than straw bedding to pens that year. There was a significant interaction between bedding type and location for pen surface gravimetric moisture and slope in 1999. Higher pen surface gravimetric moisture and slope for the bedding pack location of straw-bedded pens reflects absorption properties of straw and suggests that straw formed high mounds in the bedding pack locations.

Effects on Hydrological Response

Bedding type significantly affected initial abstraction in 1998 (table 2). The trends in 1999 for initial abstraction and time to initial ponding were opposite compared to 1998. The times for full ponding were similar for both bedding types in 1998, the only year for which data were available.

Location significantly affected initial abstraction in 1998, when bedding locations had greater initial abstractions than pen floor locations (table 2), but not in 1999. Although not significantly different, time to initial ponding and time to full ponding were higher for bedding pack locations than for pen floor locations in both years of the study (table 2). Time to initial ponding was 33% and 55% longer for bedding locations than for pen floors in 1998 and 1999, respectively. Time to full ponding was 29% longer for bedding locations than for pen floor locations in 1998, the only year for which these data were available. There were no interaction effects for initial abstraction, initial ponding, or full ponding in either year.

Bedding type had a significant effect on time to collect 2, 4, 6, and 8 L of runoff in 1998 (table 3), with longer times recorded to collect runoff from straw-bedded pens than from wood chip bedded pens. In 1999, this trend was reversed but was not significant. Location had a significant effect on time to collect 2, 4, 6, 10, and 12 L of runoff in 1998 and 1999 when it took longer to collect these volumes of runoff from bedding pack than from pen floor locations. Location also had a significant effect on time to collect 8 L of runoff in 1998, with the trend of a longer time to collect runoff from bedding pack than pen floor locations following the same trend as for the other volumes of runoff collected that year. There were no

Table 2. Means of selected hydrological responses for feedlot-pen component runoff.[a]

		Bedding Type			Location		
Parameter	Year (n =)	Straw	Wood chips	P > F	Bedding pack	Pen floor	P > F
Initial abstraction (mm)	1998 (12)	12.3 a	11.1 b	0.0117	15.7 a	9.6 b	0.0003
	1999 (8)	14.6	18.2	0.3030	19.4	13.4	0.0975
Initial ponding (s)	1998 (12)	456	409	0.4990	494	371	0.1007
	1999 (8)	817	925	0.6107	1059	684	0.0947
Full ponding (s)	1998 (12)	830	837	0.9573	939	728	0.1518
	1999		(No data)			(No data)	

[a] Means between years for each bedding type and location combination that are not followed by letters are not significantly different (P ≤ 0.05).

Table 3. Minutes to collect specific volumes of feedlot-pen component runoff (mean ±standard error).

Year	Runoff (L)	Bedding Type			Location			Interaction
		Straw	Wood chips	P > F[a]	Bedding pack	Pen floor	P > F[a]	P > F
1998	2	17.7 ±1.77	14.5 ±1.53	0.0149*	19.5 ±0.84	12.8 ±1.17	0.0003*	0.9216
	4	20.3 ±1.85	14.2 ±1.63	0.0288*	22.2 ±0.82	15.2 ±1.20	0.0004*	0.9640
	6	22.7 ±1.87	19.5 ±1.65	0.0302*	24.6 ±0.86	17.5 ±1.20	0.0004*	0.9606
	8	24.8 ±1.87	21.7 ±1.70	0.0384*	26.8 ±0.82	19.7 ±1.28	0.0005*	0.9184
	10	26.9 ±1.89	23.9 ±1.73	0.0513	29.0 ±0.77	21.8 ±1.32	0.0006*	0.8322
	12	29.0 ±1.91	26.1 ±1.81	0.0742	31.2 ±0.73	23.9 ±1.40	0.0009*	0.7298
1999	2	21.9 ±2.17	22.8 ±2.24	0.7596	25.4 ±1.94	19.2 ±1.73	0.0494*	0.5098
	4	24.6 ±2.24	25.6 ±2.11	0.7439	28.1 ±1.90	21.9 ±1.76	0.0450*	0.4188
	6	26.7 ±2.18	27.9 ±2.04	0.6548	30.2 ±1.83	24.1 ±1.73	0.0432*	0.3811
	8	32.3 ±4.57	30.1 ±1.97	0.6370	36.6 ±4.39	26.2 ±1.70	0.0530	0.2165
	10	30.6 ±2.15	32.2 ±1.90	0.5430	34.3 ±1.76	28.3 ±1.69	0.0374*	0.3291
	12	32.4 ±2.13	34.2 ±1.85	0.4994	36.2 ±1.72	30.2 ±1.68	0.0342*	0.3326

[a] * = significant when P ≤ 0.05.

interaction effects for time to collect specific volumes of runoff in 1998 or 1999.

The significantly longer times to collect 2 to 8 L of runoff from straw-bedded pens than wood chip bedded pens in 1998 were likely due to higher abstraction values of the straw-bedded pens compared to pens bedded with wood chips. In 1998, straw-bedded pens had significantly different initial abstractions than pens bedded with wood chips. When the data from 1998 and 1999 are combined, feedlot pens had an average initial abstraction value of 14.1 mm. Kennedy et al. (1999) reported initial abstraction values of up to 25 mm for a commercial feedlot in east-central Alberta. It is likely that there were more frequent additions of bedding for straw-bedded pens. Combined with the greater surface roughness of the bedding pack locations, lower initial moisture content, and lower bulk density of fresh straw than wood chips, this likely increased the retention, infiltration, and absorption of moisture. Once saturated, water in straw can transfer from capillaries into tissue, allowing further additions of water (Schofield, 1988). McAllister et al. (1998) stated that for the study feedlot, cattle on straw had to be bedded 20 times, compared to 14 times with wood chips, during a six-month period in 1998. The greater density of the wood chips meant that approximately three times more bedding material (by wet mass) was used per pen (McAllister et al., 1998).

The significantly shorter times to collect specific volumes of runoff from pen floor than bedding pack locations in both years were likely due to thinner manure layers, lack of bedding material, higher bulk density, and lower surface roughness on the pen floor. Thinner manure layers on pen floors absorbed less water than thicker manure layers on bedding packs. In addition, the lack of bedding material on pen floors resulted in less capacity of pen floors to absorb moisture, compared to bedding pack locations. This was reflected in initial abstraction values for bedding pack locations that were 62% higher in 1998 and 44% higher in 1999 than those from pen floors. There was likely less infiltration into the denser pen floors than into the less-dense bedding packs. Bedding pack locations were significantly rougher than pen floor locations in both years, allowing water to pond and later infiltrate into bedding pack locations. In contrast, precipitation falling on the smoother pen floors did not pond and therefore had less potential for infiltration.

Bedding type had no significant effect on runoff coefficients in both years of the study (table 4). Location had a significant effect on runoff coefficients when 2, 4, 6, 8, 10, and 12 L of runoff had been collected in 1998 and when 6, 8, 10, and 12 L of runoff had been collected in 1999. Runoff coefficients for pen floor locations were higher than those for bedding pack locations in both years of the study. There were no interaction effects for runoff coefficients when specific volumes of runoff had been collected in either year of the study.

Runoff coefficients increased the longer the simulation ran (table 4). This was expected, because initially all the applied water was absorbed and infiltrated into the bedding

Table 4. Runoff coefficients for feedlot-pen component runoff (mean ± standard error).

Year	Runoff (L)	Bedding Type			Location			Interaction
		Straw	Wood Chips	P > F	Bedding pack	Pen floor	P > F[a]	P > F
1998	2	0.13 ±0.02	0.16 ±0.02	0.0578	0.12 ±0.004	0.18 ±0.01	0.0010*	0.3888
	4	0.23 ±0.02	0.27 ±0.03	0.0867	0.20 ±0.007	0.30 ±0.02	0.0007*	0.6089
	6	0.31 ±0.03	0.36 ±0.03	0.0585	0.27 ±0.01	0.39 ±0.02	0.0009*	0.5726
	8	0.37 ±0.03	0.43 ±0.03	0.0662	0.33 ±0.01	0.46 ±0.03	0.0011*	0.5780
	10	0.42 ±0.03	0.48 ±0.04	0.0740	0.39 ±0.01	0.52 ±0.03	0.0012*	0.5128
	12	0.47 ±0.04	0.52 ±0.04	0.1143	0.43 ±0.01	0.57 ±0.03	0.0015*	0.4786
1999	2	0.11 ±0.01	0.10 ±0.01	0.5947	0.09 ±0.01	0.12 ±0.01	0.0735	0.2753
	4	0.19 ±0.02	0.18 ±0.02	0.6254	0.16 ±0.01	0.21 ±0.02	0.0588	0.2149
	6	0.27 ±0.02	0.25 ±0.02	0.4946	0.23 ±0.02	0.29 ±0.02	0.0411*	0.2058
	8	0.31 ±0.03	0.30 ±0.02	0.8690	0.26 ±0.03	0.35 ±0.02	0.0331*	0.1169
	10	0.38 ±0.03	0.35 ±0.02	0.3826	0.33 ±0.02	0.40 ±0.02	0.0318*	0.1965
	12	0.42 ±0.03	0.40 ±0.02	0.4049	0.37 ±0.02	0.45 ±0.03	0.0422*	0.2005

[a] * = significant when P ≤ 0.05.

Table 5. Runoff rates (mm h^{-1}) for feedlot-pen component runoff (mean ±standard error).

Year	Runoff (L)	Bedding Type			Location			Interaction
		Straw	Wood chips	P > F	Bedding pack	Pen floor	P > F[a]	P > F
1998	2	16.9 ±3.1	15.5 ±1.2	0.5526	12.3 ±1.7	20.0 ±1.6	0.0087*	0.1689
	4	23.1 ±2.9	22.4 ±1.4	0.8190	19.3 ±1.6	26.3 ±1.7	0.0177*	0.2554
	6	29.8 ±2.3	29.9 ±1.3	0.7055	26.8 ±1.4	31.9 ±1.7	0.0563	0.3839
	8	35.4 ±2.3	35.3 ±1.3	0.9860	33.2 ±1.6	37.5 ±1.8	0.1266	0.3896
	10	41.6 ±2.2	41.7 ±1.5	0.9598	40.2 ±1.7	43.3 ±1.8	0.2825	0.4292
	12	47.9 ±2.2	49.2 ±1.7	0.6580	47.1 ±1.9	50.0 ±1.8	0.3542	0.7515
1999	2	38.0 ±3.2	34.9 ±3.0	0.4914	37.5 ±3.4	35.8 ±3.1	0.6998	0.0903
	4	54.1 ±2.8	50.0 ±4.0	0.4194	52.2 ±2.7	52.4 ±4.0	0.9596	0.3120
	6	62.8 ±3.6	54.6 ±3.6	0.1656	60.4 ±3.6	58.1 ±4.3	0.6720	0.4007
	8	63.1 ±4.3	58.9 ±4.7	0.5645	61.8 ±4.1	60.7 ±5.0	0.8767	0.9011
	10	65.7 ±4.0	61.2 ±4.6	0.5117	63.5 ±4.0	64.0 ±4.7	0.9409	0.9148
	12	66.6 ±4.7	62.9 ±4.6	0.6232	66.5 ±4.9	63.6 ±4.6	0.6944	0.7479

[a] * = significant when P ≤ 0.05.

pack and pen floor. Absorption and infiltration continued as long as surface material was not saturated and application rates did not exceed infiltration rates. Once application rates exceeded infiltration rates, depressional storage began to fill. When the shallowest depressions were full, they overflowed and runoff began, which began to increase runoff coefficients. There were no significant bedding type and location interactions for hydrological response.

Bedding type had no significant effect on runoff rates in 1998 or 1999 (table 5). Location had a significant effect on runoff rates when 2 and 4 L of runoff had been collected in 1998, but there were no significant differences between the two locations for runoff rates in 1999. The trend was for lower runoff rates from bedding pack than from pen floor locations in 1998, but in 1999 runoff rates from bedding pack and pen floor locations were similar. For both years of the study, there were no interaction effects for runoff rates when specific volumes of runoff had been collected.

Runoff rates in excess of the application rate of 54 mm h^{-1} imply release of water from depressional storage. The average runoff rate did not exceed the application rate before 12 L of runoff had been collected in 1998 (table 5), but did so after. The average runoff rate exceeded the application rate after 4 L of runoff had been collected in 1999. The volume of water released from depressional storage varied from 0.12% to 12% of the total water applied during the simulation in 1998 and varied from 0.25% to 10% in 1999.

Factors Affecting Time to Initial Runoff

Depth of manure significantly affected the time to start of runoff from straw-bedded pens in 1998 (table 6), whereas compacted layer bulk density and depth of manure significantly affected the time to start of runoff for pens bedded with wood chips in 1998. Pen surface roughness significantly affected the time to start of runoff from pens bedded with straw in 1999, whereas depth of manure and hardpan bulk density significantly affected the time to start of runoff for pens bedded with wood chips in 1999.

In 1998, slope had a significant effect on time to start of runoff for pen floor locations, while in 1999, depth of manure and compacted layer moisture content were significant variables affecting the time to start of runoff from pen floor locations (table 6). No variables met the 0.15 level of significance for entry into the model for bedding pack locations in 1998 or 1999.

Time to start of runoff has been documented to be affected by the depth of the manure (Watts and McKay, 1986), antecedent moisture content of the pen (Clark et al., 1975), pen slope (Gilbertson et al., 1980), and pen surface roughness (MacAlpine et al., 1996). Density of the compacted layer might also affect time to start of runoff. As soil density increases, pore size and volume decrease, resulting in reduced infiltration. This reduced infiltration acts as a barrier and causes the manure layer above to retain moisture.

Depth of manure, slope, compacted layer bulk density, and surface roughness affected the time to start of runoff; however, the variables that were significant varied between the two years of the study. This makes predictions of time to start of runoff based on these variables difficult. Manure depth is likely the most useful variable for making predictions based on bedding type, as it was significant in 1998 for straw bedding and in both years for wood chip bedding. Compacted layer bulk density might also be a useful indicator of time to start of runoff when pens are bedded with wood chips.

Table 6. Stepwise regression equations for feedlot-pen component runoff, where T = time to start of runoff.

Year	Bedding	Model R^2	Pr > F[a]	Equation
1998	Straw	0.7906	0.0177*	T = 485.46 + 52.21 × manure depth (cm)
1998	Wood chips	0.9910	0.1352	T = 7.20 + 233.75 × compacted layer bulk density (Mg m^{-3}) + 36.33 × manure depth (cm)
1999	Straw	0.6753	0.0123*	T = 148.30 + 71.92 × pen surface roughness (%)
1999	Wood chips	0.6849	0.1268	T = −293.65 + 165.03 × manure depth (cm) − 20.88 × compacted layer bulk density (Mg m^{-3})

Year	Location	Model R^2	Pr > F	Equation
1998	Pen floor	0.6161	0.0644	T = 1223.44 − 165.55 × pen slope (%)
1999	Pen floor	0.1632	0.0581	T = −596.05 + 43.44 × hardpan gravimetric moisture (%) + 68.98 × manure depth (cm)

[a] * = significant when P ≤ 0.05.

General Discussion

It is postulated that the release of water from depressional storage resulted in average runoff rates exceeding application rates at times. Wet, uncompacted pen surfaces allow cattle hooves to create depressions in pen surfaces that can fill with water. This water is held as depressional storage. Continued raindrop impacts and saturation of manure cause ridges to collapse, releasing the stored water. This released stored water combines with the applied rainfall to create runoff rates in excess of application rates. Lott et al. (1994) also observed this phenomenon on Australian feedlots. Once the ridges collapsed, the feedlot surface would be smoother and able to retain less water than before the rainfall event. Hence, the actual surface roughness is likely altered during a rainfall event. It is suspected that this smoothing effect would be more prominent in the pen floor area than in the bedding pack area, as the bedding materials would likely impart some structural stability to the manure depressions.

The amount of precipitation received by the feedlot affects the bedding regime. This would have implications on the effect of bedding type and within-pen location on feedlot pen antecedent properties and hydrological response. If it is desirable to make predictions about the hydrological response of feedlot pens, then the amount of precipitation the feedlot receives; type, amount, and frequency of bedding; within-pen location; manure depth; pen surface roughness; pen slope; compacted layer bulk density; and moisture content are factors that may need to be considered.

Two years of data provided an insight into the effects of bedding material and within-pen location on hydrological response, but additional years of data gathering and analysis are required to better understand the response of the feedlot under varying annual precipitation amounts. Data gathered over several years, when antecedent conditions vary, should enhance our understanding of the effect of bedding type and within-pen location on runoff. Our results indicate the tenuousness of conclusions based on only two years of study and especially based on only a single year.

Conclusions

Bedding type had no significant effect on the same antecedent factors or hydrological parameters across both years of this study. However, location within the pen significantly affected manure depth and gravimetric moisture content, clod bulk density, and slope and roughness of the pen surface.

Runoff was initiated sooner from pen floor locations than from bedding pack locations. Once runoff started, various factors affected the time for specific volumes of water to run off. The feedlot pen surface roughness increases during a precipitation event due to the movement of cattle, whose hooves create depressions. Once depressions within the manure pack are filled and the saturated walls of the depressions collapse, the stored water is released and contributes to runoff. Hence, runoff coefficients can change quickly to exceed the water application rate, and will vary depending on whether this release has occurred.

Treatment effects in this study were dependent on year and were inconsistent over the two years of study. Therefore, the effect of these treatments needs to be investigated over a greater number of years.

Acknowledgements

The assistance of the following people was greatly appreciated: Bruce Beasley, Brian Handerek, Sean Robison, Ken Coles, and Michael Verhage, who conducted the field and laboratory work for this study; Ian Walker and Wendi Smart, who coordinated the bedding of the cattle; and Toby Entz, who provided statistical advice. Funding for this study provided by the Canada-Alberta Beef Industry Development Fund is gratefully acknowledged.

References

Allison, F. E., and M. S. Anderson. 1951. The use of sawdust for mulches and soil improvement. USDA Circular No. 891. Washington, D.C.: USDA.

Blake, G. R. 1965. Bulk density. In *Methods of Soil Analysis*, 32-35. Agronomy No. 9, Part 1. Madison, Wisc.: American Society of Agronomy.

Clark, R. N., A. D. Schneider, and B. A. Stewart. 1975. Analysis of runoff from Great Plains feedlots. *Trans. ASAE* 18(2): 319-322.

Gilbertson, C. B., R. N. Clark, J. C. Nye, and N. P. Swanson. 1980. Runoff control for livestock feedlots: State of the art. *Trans. ASAE* 23(5): 1207-1212.

Kennedy, B., R. N. Coleman, G. G. Gillund, B. Kotelko, M. Kotelko, N. MacAlpine, and P. Penney. 1999. Volume 1: Quantity and quality of rainfall and snowmelt runoff from pens. In *Feedlot Runoff.* CAESA Research Program Project Number RES-109-94. Vermilion, Alberta, Canada: Alberta Agriculture, Food and Rural Development.

Lott, S. C., R. J. Loch, and P. J. Watts. 1994. Run-off from Australian feedlots. In *Proc. Great Plains Animal Waste Conference on Confined Animal Production and Water Quality,* 47-53. GPAC Publication No. 151. Denver, Colo.: Great Plains Agricultural Council.

MacAlpine, N., G. Gillund, B. Kennedy, R. Coleman, W. Sawchuck, B. Kotelko, S. Ahmed, and L. P. Penny. 1996. Hydrology of a feedlot. Canadian Society of Agricultural Engineering Annual Conf. Paper No. 96-203. Lethbridge, Alberta, Canada: Agricultural Institute of Canada.

McAllister, T., F. Larney, J. Miller, J. Yanke, and I. Walker. 1998. Wood chip vs. straw bedding. *The Canadian Cattleman Magazine* 61(10A): 26-30.

McNeil R. L., and B. J. Sawyer. 1998. *Land Resource Planning with a Focus on Manure Management.* Edmonton, Alberta, Canada: Alberta Agriculture, Food and Rural Development, and LandWise, Inc.

Mielke, L .N., and A. P. Mazurak. 1976. Infiltration of water on a cattle feedlot. *Trans. ASAE* 19(2): 341-344.

Miller, J. J., N. J. Sweetland, and F. J. Larney. 2000. Impact of fresh manure and compost containing straw and wood chip bedding on soil physical properties. Technical Report, Project No. 990071: Farming for the Future Research Program. Lethbridge, Alberta, Canada: Agriculture and Agri-Food Canada.

Miller, J. J., E. C. S. Olson, D. S. Chanasyk, B. W. Beasley, L. J. Yanke, F. J. Larney, T. A. McAllister, B. M. Olson, and L. B. Salinger. 2006. Bedding and within-pen location effects on feedlot pen runoff quality using a rainfall simulator. *J. Environ. Qual.* 35(5): 505-515.

Miner, J. R., L. R. Fina, J. W. Funk, R. I. Lipper, and G. R. Larson. 1966. Stormwater runoff from cattle feedlots: Management of farm animal wastes. In *Proc. National Symposium on Animal Waste Management*, 23-27. ASAE Publication No. SP-0366. St. Joseph, Mich.: ASAE.

Ponce, V. M. 1989. *Engineering Hydrology: Principles and Practices.* Englewood Cliffs, N.J.: Prentice Hall.

Saleh, A. 1993. Soil roughness measurement: Chain method. *J. Soil Water Cons.* 48(6): 527-529.

SAS. 1989. SAS/STAT Users' Guide. Version 6. Vol 2. 4th ed. Cary, N.C.: SAS Institute, Inc.
Schofield, C. P. 1988. Water absorption by spring-barley bedding straw. *Biol. Wastes* 26(2): 133-144.
Tossell, R. W., W. T. Dickinson, R. P. Rudra, and G. J. Wall. 1987. A portable rainfall simulator. *Canadian Agric. Eng.* 29(2): 155-162.
Watts, P .J., and M. E. McKay. 1986. Simulation modeling of cattle feedlot hydrology. In *Conf. on Agricultural Engineering*, 393-398. Barton, ACT, Australia: Institute of Engineers.