Water Balance of a Prairie Cattle Feedlot Pen

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Abstract

The overall purpose of this study is to define the water balance of feedlot pens in a Saskatchewan cattle feeding operation. Although the initial intention of the study was focused upon an active feedlot circumstances resulted in our year of analysis being on an recently abandoned feedlot. During the study year (Sept 2003 to Aug 2004) there was very little precipitation until May 2004. Weirs in operation for only part of the summer recorded no runoff. Winter precipitation was very low (34 mm) and there was no observed runoff from it. Runoff models, using lab and field parameters found that at the most there might have been runoff from only one event, that of 26 mm 24 hr rainfall, and this would have only occurred on a pen scraped of manure. Drainage beneath 60 cm soil depth was zero mm. Of the 339 mm of precipitation that fell during the study year, some of it was stored within the manure pack and the rest lost as evaporation.

Introduction

Current provincial siting regulations require design of holding ponds for at least 7.5 cm (3 inches) of runoff from the contributing area. Many jurisdictions use the volume of a 1 in 25 year-24 hour rainfall event to determine the holding pond volume. For Saskatchewan this corresponds closely to 7.5 cm. As it stands now, it is unknown if this regulation is sufficient or overcompensates for the actual runoff from feedlot penning areas. ***The objective of this study is to quantify the water balance of a field lot pen.*** Evaluation of a water balance involves determination and measurement of processes that add water (input) or remove water (output) from the system along with changes in water storage of components within the system. Although it was originally the intention of quantifying the water balance of an active feedlot circumstances resulted in the study year being for an inactive feedlot. The following water balance components and processes were determined or measured for a one year period: precipitation, evaporation, runoff, infiltration soil, change in soil moisture to a depth of 0.60 m, and water draining below a depth of 0.6 m. The findings from this study will be later used to develop a daily soil water balance model for cattle feedlot pens that incorporates climatic, texture, and water input conditions so as to determine the occurrence and amount of runoff.

Materials and Methods

The study site was the River Ridge feedlot, which is located approximately 20 km south of Eston and about 50 km SE of Kindersley on the north side of the South Saskatchewan River. The feedlot was first established in 1996 as a community co-op venture consisting of 8 pens, each 75 by 75 m in area. During 2002 another 8 pens were established immediately to the north of the previous pens. Construction consisted of removal of the top soil and grading the pens such that runoff collected in holding ponds on the perimeter of the feedlot area. .

Our study took place in two pens, one that was first stocked in 1996 and another first stocked in 2002. Stocking density of each the two study pens had been approximately 100 backgrounding cattle weighing about 360 kg each. The pens were 75 m by 75 m in area, thus the stocking density was approximately 56 m^2 per head. The stocking density used at the feedlot was less than that of other North American feedlots, which is generally between 7 and 16 m^2 per head (Davis, 2002). Bedding consisted of straw. The pens were cleaned in the fall of each year. There were cattle present in pen 4 until August 2003 and July of 2003 in pen 6. Our study year was from Sept 1, 2003 until Aug 31, 2004.

Table 1. Parameters Measured and Methods Used for Study

Parameter	Instrumentation or Method	Reference
Rain intensity and amount	Texas tipping bucket	
Daily snowfall	Kindersley	Environment Canada
Potential evapotranspiration	Standardized ET	ASCE 2002
Potential evapotranspiration	Hargreaves	ASCE 2002
Infiltration, Ksat	Double ring infiltrometer	
Infiltration, Ksat & runoff, measured	Guelph Rainfall simulator	Tossell 1987
Infiltration & Runoff, calculated	Green-Ampt	Chu 1997
Runoff actual, measured	V-notch weir	
Runoff, calculated	USDA SCS	Schwab et al., 1996
Snowmelt runoff	Observation and calculated	Gray et al., 1985
Ksat	undisturbed cores	falling head
Drainage	chloride tracer	Maule and Fonstad (2002)
Bulk density (soil, manure)	undisturbed cores, clod, settling	
Moisture content	undisturbed & disturbed cores, TDR	

Results

Soil Properties: The texture of the top 60 cm of the feedlot pens was a loam (18% clay and 51% sand). The top 5 cm of soil had an organic carbon content of 0.68%. The bulk density of the soil was highest in the upper 10 cm (1.67 g/cm^3) and was 1.35 g/cm^3 at 20 to 25 cm depth.

Manure Properties: During the study period there were no cattle in the pens, however the manure pack had been left at our request. The manure pack at the start of the study and in May 2004 was generally in a dry state. Its average thickness was 11 cm consisting of about 6 cm of dry loose granular (several mm to 10 cm 'pieces') material overlying about 5 cm of hard compacted manure. The granular layer, upon sampling, was very dry and had a dry bulk density of 0.44 g/cm^3. Upon saturation (in the lab) the volumetric moisture content increased to 0.82 m^3/m^3 and the bulk density decreased to 0.36 g/cm^3 due to expansion.

Climate: During the study period (Sept 1, 2003 to Aug 31, 2004) the feedlot climate station was operational only 45% of the time. Equipment failures combined with distance resulted in an incomplete data set. To supplement the missing data, daily temperature and precipitation was used from Kindersley (Environment Canada), after correction. During the one year study period the average temperature was 3.0°C and the total precipitation was 339 mm. This was comparable to the long term average (1971-2000) of 2.9 °C and total precipitation of 326 mm. The warm season (April thru October) for the study period was slightly cooler and wetter than normal (11.2°C as compared to 11.8°C and 305 mm as compared to 254 mm. Snowfall (as measured at Kindersley) was only 34 mm of water, lower than long term normal of 59 mm.

Wetting and Drying events: During the operational time of the feedlot met station the greatest intensity recorded on the tipping bucket was 4.5 mm in 30 minutes on June 11, 2004. There were 46 days with rainfall greater than 1.0 mm (including data supplemented from Kindersley) of which there were 11 events larger than 10 mm/day of which the largest 4 events were 26, 19, 19, and 16 mm on June 3, June 11, Aug 4, and Aug 7 respectively. Two wet periods occur during the study period (Fig 1); June 2-12 (96 mm) and July 27 to Aug 7 (71 mm) (Fig. 1). The study year started off very dry (Aug 2003 had only 17 mm) and continued so until May 2004 by which only 59 mm had occurred with 34 mm of it during winter. Potential evapotranspiration (PET) for the study year was 733 mm (Fig. 1). From analysis of longterm Kindersley rainfall data (1911 to 2004) it can be expected that a maximum 24 hour rainfall of 85 mm will occur once in 30 years and a rainfall of 35 mm can be expected once a year.

Recorded and observed runoff events: The weir was in operation for only a short time (July 1 2004 to Aug 31, 2004), during which there were no runoff events recorded. During this period there were 5 rainfall events greater than 10 mm/d of which the largest was 19 mm on Aug 4. During the study year there were no observed runoff events, during site visits, nor any evidence of (from ponded water in the storage pond or that of fresh erosion rills in the sides of the storage pond). The snowpack was very thin and a site visit during spring melt revealed no runoff from the pens into the storage ponds.

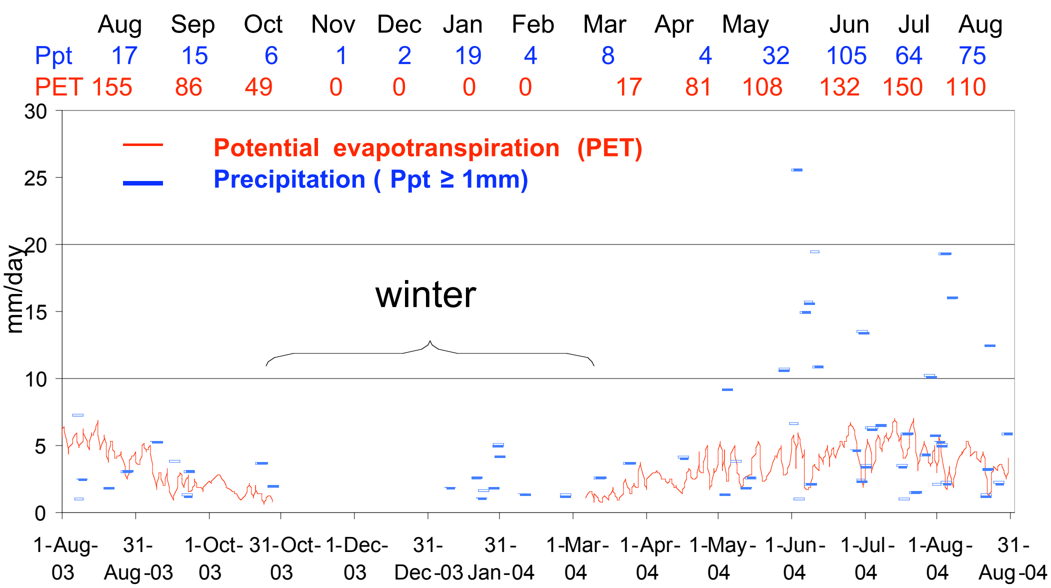

Figure 1. Daily potential evapotranspiration and precipitation, Aug 1 2003 to Aug 31 2004. Values in top are in mm/month.

Drainage: Chloride concentrations in the upper 10 cm of soil underlying the manure pack was between 337 and 481 mg/L (2:1 extract) and reduced to 4 and 51 mg/L by 40 to 50 cm depth. There was some variation with depth, thus it is difficult to interpret what was background Cl. Within the nearby agricultural field Cl concentrations were between 4 and 7 mg/L to a 2 m depth. Based upon previous work (Maule and Fonstad 2002) seepage rates are very low (2 to 8 mm/yr) and the higher chloride concentrations at depth (eg., 150 mg/L) may not likely to be due to manure; it could be due to parent material, construction, or old farmstead buildings. Given the dry year experienced it is unlikely that there was any drainage within the study year.

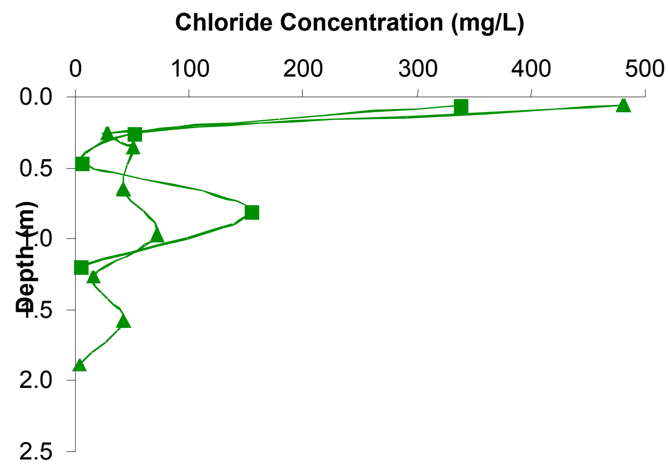

Figure 2. Chloride concentration of pen 4 with depth.

Changes in soil moisture storage: Soil samples taken in September 2003 showed bare soil and soils with a manure pack on top having 113 mm and 124 mm of moisture in the upper 60 cm respectively. By Aug 24, 2004 the upper 60 cm of bare soil had 137 mm of moisture, while that of the upper 60 cm of soil with an overlying manure pack had 116 mm. Although there was definitely a drying trend from Sept 2003 until June 2004, the manure pack and bare soil gained moisture from the July and August rains (Fig. 3). Manure pack and soil samples taken for moisture content from July 6 to Oct 6, 2004 showed the manure pack increasing in moisture content from July 19 to Aug 24 by 50 mm, while the soil beneath the manure pack increased by 4 mm, and soil with no manure pack, by 17 mm (Fig. 3). For soil at the depth interval 40-60 cm change during the same period was 0 mm. During this period, rainfall was 89 mm with most of it occurring from July 19 to Aug 10. Potential evapotranspiration was 144 mm.

Instrumental infiltration and saturated hydraulic conductivity; Steady-state infiltration on the feedlot manure pack, as measured with the double ring infiltrometer and the rain fall simulator was 5.5×10^{-3} cm/s and 8.9×10^{-4} cm/s respectively. Laboratory cores provided saturated manure hydraulic conductivity values of 3.5×10^{-4} cm/s. The rainfall simulator measured steady-state infiltration into the scraped soil surface of 8.1×10^{-3} cm/s whereas the lab Ksat values were 3 orders of magnitude lower, at 5.1×10^{-6} cm/s. It was difficult to install the metal sides of the rainfall simulator and lateral flow could have accounted for the higher rates. The lab measurements were on undisturbed clods and the lack of naturally occurring cracks could have also resulted in lower rates than would have occurred in the field.

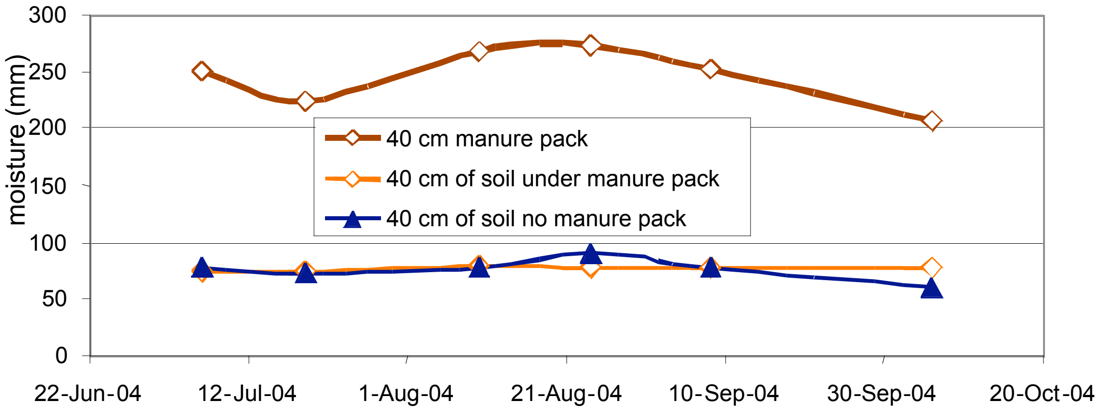

Figure 3. Moisture content of manure, soil underlying manure and bare soil of feedlot pens.

Instrumental rain and runoff; Where the rainfall simulator tests (at rain rates between 34 and 55 mm/hr) were done on the manure pack it generally took at least 2 hrs (and in once case 8 hrs) to achieve runoff. This was due to the dry state of the manure pack, which absorbed much of the rainfall. Rainfall simulator tests on the bare pen soil (manure was scraped away) resulted in runoff occurring within 1 to 6 minutes.

Modeled infiltration and runoff; Given the incomplete data set by the weir, two models (Green-Ampt infiltration and SCS runoff) were used to determine whether or not runoff might have occurred from the four heaviest rains (16, 19, 19, and 26 mm). Using the Green-Ampt equation obtained reasonable fit (time to occurrence of runoff and runoff rate) rainfall simulation runoff for soil with a Ksat of 5.1×10^{-5} cm/s and for a manure Ksat of 3.5×10^{-4} cm/s. Analysis of Kindersley and Saskatoon rainfall intensity-duration data (Environment Canada) indicates that for 24 hr rain amounts of 19 to 25 mm, that the median 5 minute intensity rainfall intensity will be of about 20 mm/hr, with 80% of the total rain amount falling within 6 hrs. The Green-Ampt method indicates that for these four storms there would be no runoff for the manure pack, wet or dry and for a bare packed soil surface there would only be at the most 5 mm runoff if the antecedent soil moisture was close to saturation.

The USDA Soil Conservation Service (SCS) runoff method have been used by others to model feedlot runoff (Kennedy, 1999; Miller et al., 2003) and found that curve numbers varied between 52 and 97 depending on antecedent moisture, stocking density, and storage values of the manure pack. As no runoff was recorded during our study period we looked at the effects of using a SCS curve number of 60, to represent dry manure and that of 90 for a scraped pen. The 24 rainfall required to produce 5 mm of runoff for a SCS curve number of 60 was 50 mm and for a SCS curve number of 90 was 20 mm. A one in 30 year rainfall of 85 mm will produce about 20 mm of runoff from a dry manure pack (SCS of 60) and 80 mm from a pen soil surface (SCS of 90).

Findings

We considered the soil and manure water balance of an inactive feedlot during the period of Sept 1, 2003 to Aug 31, 2004. The cattle were taken from the pens in July 2003. Analyses are not completed for the manure pack moisture contents, but the following water balance components were determined for the one year period:

Total precipitation: 339 mm (of which 34 mm was snow)
Bare soil surfaces in feedlot pens

- change in soil moisture to 60 cm: 23 mm gain
- probable runoff: 5 mm
- probable drainage: 0 mm from rains
- evaporation: 311 mm (=339 – 23 – 5)

Manure pack in feedlot pens

- change in underlying soil moisture to 60 cm depth: -8 mm
- change in manure pack moisture content: unknown
- probable runoff: 0 mm
- probable drainage: 0 mm
- evaporation: 339 mm

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