FEEDLOT RUNOFF: Volume 1: Quantity and quality of rainfall and snowmelt runoff from pens

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EXECUTIVE SUMMARY

The runoff study was conducted at Highland Feeders Ltd. feedlot north of Vegreville from 1994 to 1996. During this time the feedlot population increased from about 12,000 head to 25,000 head.

This study characterised pen runoff quantity and quality from an operating beef feedlot in Alberta's parkland. The main objectives of the study were to:

1. measure the runoff volume resulting from rainfall events at the feedlot site

2. measure chemical parameters including, but not limited to, pH, calcium, sodium, potassium, chloride, COD, TKN, NH_3-N, and phosphorus, and

3. measure microbiological parameters including heterotrophic plate count, faecal coliforms, and faecal enterococci.

Runoff was collected and analysed from four groups of pens in the feedlot. Two of these groups of pens were newly developed after the study started. As well, samples of runoff were collected from the runoff holding pond.

During the course of the study other parameters were also investigated. A soils investigation was conducted through the feedlot floor to estimate infiltration. The land area where the runoff was applied by irrigation was monitored for microbiological die-off and chemical changes.

The literature review also indicated that a runoff retention basin required a settling basin in front of it to remove transported solids from the runoff. These solids can be removed mechanically and their volume does not reduce the capacity of the runoff storage basin. Sizing the runoff storage requires that total seasonal runoff be considered.

Literature reviewed also indicated that feedlot runoff contained a variety of plant nutrients and salts. Utilization of the runoff must consider the effects of salts on the crops and soils to which it is applied. High irrigation rates can result in the build-up of salts in the soil with subsequent soil damage and reduced cropping choices.

Summary of Results

Hydrology. During the period of the study, two types of storm events were observed: a short-duration high-intensity storm and a long-duration low-intensity storm. The first type of storm produced a small amount of runoff immediately; the second type of storm produced runoff after a time delay of about 24 hours. During this time the surface of the feedlot absorbed moisture and runoff began when the surface was saturated. Approximately 25 mm of rainfall was needed to saturate the surface. Runoff yield from these events ranged from 22.8% to 73.7% of the rain that fell on the pens.

Snowmelt runoff was not measured during this study. Before snow melted, feedlot management implemented a pen management strategy that removed manure and snow prior to snowmelt. This produced dry pens in a short period.

Chemistry. Runoff samples were collected and analysed for chemical parameters. In general terms, chemical concentrations and suspended solids were higher in the runoff than in the runoff storage pond.

Microbiology. Heterotrophs, faecal enterococci and faecal coliforms were measured in runoff samples and in the runoff storage pond. One surprising result was that similar microbes were found in the runoff from a new site that never had cattle and the levels were in the same order of magnitude as nearby active pens holding cattle.

Conclusions

1. Holding pond size depends on total yearly rainfall at the site and on the management practices of emptying the stored runoff. Sizing criteria for catch basins has focussed on severe single event storms. In light of the runoff characteristics of feedlot pen soils and the annual one-time emptying of catch basins, runoff yields from a critical wet year may represent data more appropriate to currentdesign requirements.

2. A protocol for land application of stored runoff is needed. This protocol must consider runoff and soil chemistry as well as plant uptake of nutrients and response to any sodium contained in the runoff.

3. Manure rock removal practices and pen scraping must not interfere with any impervious layers that develop at the base of the manure pack.

4. Feedlot runoff contains a number of nutrients and salts. The levels found in the runoff are variable, both during the year and within storm events.

Literature Review

As part of this study an extensive literature review was conducted. This review provided a conceptual model of a feedlot floor as an impervious layer, overlain by a sponge-like material that soaks up water from a rainfall or snowmelt event, before runoff begins. Runoff from both rainfall and snowmelt depended on the intensity and duration of the event. Some of the water was retained on the pen surface in depressions created by animal feet, and in pen surface materials, and later evaporated; the remainder was runoff. Pen surfaces lost material due to transportation by water during runoff events. The more intense the storm, or water flow over the pen surface, the greater the amount of solids in the runoff. Wind erosion also removed material from pens when conditions were dry and the surface pulverized by animal feet.

MATERIALS AND METHODS

Instrumentation

Various instruments were installed at the Highland Feeders Ltd. feedlot to collect weather data, rainfall data, runoff volume data and samples of runoff for analysis. Data-loggers and automatic samplers were used to collect information and samples for each runoff event, respectively.

Rainfall and Weather. A small recreational trailer, modified to house instrumentation, was moved to the site in 1993 for use as a work area, supply storage and instrument housing. A Stephenson screen was set up adjacent to the trailer and housed a Campbell Scientific Model

207C temperature and relative humidity probe, connected to a Campbell Scientific CR10 data-logger (Anon, Campbell Scientific).

A program for the CR10 and 21X data-loggers was developed to collect daily high and low temperatures and relative humidity. Temperature and relative humidity were sampled and averaged every hour. Daily highs and lows were calculated and recorded once per day at midnight. Rainfall amounts were recorded every 15 minutes by a Qualimetrics Model 6011B (Campbell Scientific) tipping bucket rain gauge and stored on a Campbell Scientific CR10 data-logger. In addition, eight Tru-Chek (supplied by Canadian Forestry Equipment Ltd.) rain gauges were located around the feedlot and read manually once per week. A layer of cooking oil was placed in these gauges to minimize evaporation. The purpose of these rain gauges was to provide information of the variability of the rainfall over the watershed.

A Class A evaporation pan was also installed and manually read on a weekly basis. A Class A evaporation pan is 120.7 cm in diameter and 25 cm deep, and it has a stilling well to take depth readings. Ideally the water level in the pan should be within 5 cm to 7.5 cm below the rim. The evaporation pan was placed on a wooden platform and the grass in the area was trimmed regularly. In the spring, when samplers were installed, the Class A Evaporation pan was installed. The evaporation pan was filled with water to the measuring pin and checked on a regular basis. If any evaporation had taken place, the water was replaced from a calibrated reservoir. The amount of evaporation was read on a weekly basis. If there was a precipitation event there was no provision for overflow, however, the volume of precipitation was available from the rain gauges. In September/October migrating birds did consume water from the evaporation pan.

Runoff Measurement and Collection. Runoff from each set of pens was collected and directed to an outlet, then to a culvert at an extreme southerly point, and into the runoff holding pond. A stilling well, v-notch weir and a water level recording device were installed at each culvert. The weir was constructed of 6.35 mm thick plate steel with dimensions of 60 cm by 30 cm with a 90^0 V-notch, centred and 25 cm deep, and a sharpened upstream edge. The V-notch weir was fastened to the bottom of the inlet side of the culvert. A stilling well and a California shelter, to house water level recorders, were installed at each culvert. The stilling well was 1.52 m high, and had a 45.7 cm diameter. A series of perforations were made in the lower 45.7 cm of the stilling well.

Calibration of the culvert V-notch weir system was done by pumping water into the area above the culvert. The culvert was blocked with a piece of plywood until a suitable head of water (at the top of the culvert) was reached. The water was then released. A Swotter Instruments Model 2100 Current Velocity (Source) metre was used to measure flow velocity and depth at the outlet. The water head at the inlet was also measured. From these data a regression equation was developed to predict culvert flow based on head above the bottom of the V-notch at the inlet end. A listing of each culvert's unique equation is compiled in Table 2 (Appendix I).

In 1993 and 1994, Pen Area 1 emptied into its own small evaporation pond. Water levels in this small pond were recorded in an attempt to estimate runoff volumes. However, the minor variation in levels made accurate estimates impossible and good runoff data was not collected from this site until 1995 when Pen Area 1 and Pen Area 4 were set up with "V" notch weirs and data-loggers as the other sites. Consequently, data is available for Pen Areas 2 and 3 from 1993 to 1996, while Pen Areas 1 and 4 are limited to August, 1995 to 1996.

Water Level Recorders. Initially, Stevens A-71 water level recorders, complete with floats, cable and weights were installed. These instruments made an ink trace on a moving paper chart.

Proprietary software developed by Alberta Environmental Protection was used to digitize these charts. Belfort water level recorders (Portable liquid level recorder, Cat. No. 5-FW series) complete with CLA 10 turn 2W 10k Lin potentiometers (supplied by Cardinal Industrial Electronics) replaced the Sevens A-71. Output from the potentiometer was stored on Campbell CR-10 or 21-X data-loggers. Fluctuations in water level moved the potentiometers through three turns. The changes in potentiometer resistance were recorded on the data-logger. The data were retrieved by down loading the data-logger through a SC32A Interface, using PC208 Software.

A Campbell SR50 Sonic Ranging Sensor was also used to sense water depth at a weir to determine flow depth and thus be able to calculate water volume. The SR50 determined height by measuring the elapsed time to send and receive the returned echo of an ultrasonic pulse. The signal from the SR50 was routed to a CR10 data-logger.

ISCO 3700 automatic water samplers (Nortech Control Equipment (Canada) Ltd.) were used to collect water samples every 45 minutes during a runoff event. Samplers were activated by an ISCO Model 1640 Liquid Level Sampler Actuator. The ISCO 3700 used plastic sample bottles, which were impossible to sterilize. This problem was overcome by lining the bottles with "Whirl-Pak" sterile plastic bags. Bags were changed when samples were collected.

Infiltration. Two approaches were utilized to determine infiltratration under feedlot pens:

1. examination of soil profile in 30 cm increments to 1.0 m for Cl and NO_3-N concentrations that would indicate water movement from the pen surface into soil.

2. large double ring infiltrometers

Soil Coring. Two pens were randomly selected in each treatment block representing feedlot pens that had been utilized 5 years (site 1), 2 years (site 2) and 1 week (site 3) prior to sampling in October, 1996. Pens 5 and 23 were sampled in site 1, pens 43 and 52 were sampled in site 2; and pens 72 and 86 were sampled in site 3.

Soil cores, 5 cm in diameter, were extracted to a depth of 1.0 m utilizing a hydraulic core sampler mounted on a truck. Soil surface was considered to start immediately below the impervious layer under the manure pack.

In each pen a uniform grid pattern was used to remove nine cores. The first transect ran 5 m into the pen parallel to the concrete apron. Cores were taken at the mid point and 5 m in from each of the side fences. The second transect ran across the pen at the mid point and the third transect ran across the pen 5 m from the back fences, both with cores taken at the same positions along the transect as in the apron transect. Because of limited funds, only the centre core of the third transect in each pen was analyzed. See Figure ** for ___________ oxide pattern.

Each core was divided into 30 cm sections and each section was separately bagged, labeled and analyzed. Core sections started below the impervious manure layer. Samples were analyzed for Cl and NO_3-N as tracers to indicate if leaching had taken place. Both Cl and NO_3-N were known to be continually loaded to the pen surface through the cattle urine and manure.

Infiltrometers. Two sets of double ring infiltrometers were constructed from pipe. The inner ring was 390 mm in diameter, with an 8 mm wall thickness, whereas the outer ring was 744 mm in diameter with a 10 mm wall thickness. Both rings were 300 mm deep. The bottom edge of the rings was sharpened to enhance soil-ring contact. The point of a nail suspended from a board on the top of the inner ring was used as a constant reference point for water level. After initial wetting of the soil and initial readings, the infiltrometers were covered with plastic to minimize evaporation and the addition of water by precipitation.

Initial attempts to pound the infiltrometer rings into the soil for a ring-soil seal was found to be to disruptive and ineffective. As a result a technique of sealing the rings into a manually formed groove in the soil using bentonite was developed. A 10-15 mm deep groove was formed, filled with bentonite and the infiltrometer rings set into the Bentonite. The weight of the rings (24 and 54 kg) assisted in achieving a good soil-ring seal (Kennedy *et al*., 1995).

These infiltrometers required 50-60 litres of water each, for initial filling yielding a height of 190 to 200 mm. Initially water was carefully added in small volumes to minimize surface disturbance and to ensure the integrity of the soil-to-ring seal. Once the integrity was confirmed, the rings were filled to the reference point and readings begun. Initial readings were taken on a 2 to 25 minute basis for the first 2-3 hours, then at random times 24 to 72 hours apart.

Runoff Irrigation. A portion of a field (about 40 ha) adjacent to the wastewater storage pond, was irrigated with wastewater. Prior to irrigation, a benchmark area was selected, marked out and surveyed to facilitate repeated soil sampling of the same area. Soil samples were taken just prior to the irrigation on October 4, 1994, three days after irrigation, and in the following spring May 15, 1995 (eight months after irrigation). Soils samples were taken at depths of 0-15cm, 15-30cm, and 30-45cm. Each sample for analysis was derived from a composite of sixteen cores taken in a uniform grid pattern in the 30m x 30m benchmark area. Selected lab analysis was used to determine nutrient addition to the soil, salt loading and change in pH due to the effluent irrigation. Analysis of the soil included ammonium (NH_4-N), nitrate (NO_3-N), phosphate (PO_4-P), sodium (Na), potassium (K), pH, and electric conductivity (EC). Faecal coliforms, faecal enterococci and heterotrophic plate count were conducted on surface sampling, starting the day after the irrigation.

Samples of the irrigation effluent were collected by placing large sterilized pans in the field during the irrigation process. Effluent samples were analysed for calcium (Ca), sodium (Na), total K nitrogen (TKN) and total phosphorus (T-P), potassium (K), pH, faecal coliforms, faecal enterococci and heterotrophic plate count.

The effluent was applied to approximately 40 hectares with standard wheel-move irrigation equipment. About 10 cm of effluent was applied in a single application.

Analytical Methods

ISCO 3700 Portable Samplers. Runoff samples from the feedlot surface were collected using ISCO 3700 portable Samplers (Figs. 4 and 5: Appendix II). The samplers were installed on platforms, situated at each channel leading from the feedlot surfaces from May to October each year, while freezing conditions were not present. Tie down straps were used to secure the samplers to eyelets attached to the platforms. The samplers were operated with 12 V RV batteries.

To detect the presence of runoff the samplers were equipped with Model 1640 Liquid Level Actuators (set to toggle position). Once runoff was detected, and every 45 minutes thereafter, 450 mL samples were pumped into sterile 500 mL Whirlpak bags that lined the plastic sample bottles, until the sampler was disabled or all 24 bottles had been filled. Samples were collected through a small stainless steel strainer connected to the sampler by 9.5 mm ID Tygon tubing and Silastic-medical grade pump tubing. The samplers were programmed to purge the lines before and after sampling and to rinse the tubing twice before collecting the sample.

Sample events, stored by the sampler, were recorded and reset upon collection of the samples. At the time of collection, samples from the beginning to the end of a rain event were each composited in sterile labelled 1L plastic bottles. If an event had a lapse between sample collection greater than two hours, the beginning and end samples from the new group were also collected. After collection, the samples were shipped to the laboratory on ice, and analysed within 24 hours for microbiological parameters. Clean bottles with sterile liners replaced those from the ISCO 3700 portable samplers. Dirty bottles were returned to the laboratory for cleaning and bag replacement. Samples for chemical analysis were preserved as necessary and then stored at $4^{o}C$ until further analysis could be completed.

Due to lack of precipitation during the first sampling season, samples were not composited. As a result, the volume of sample was not always adequate to perform all desired analysis. We decided to composite neighbouring samples to collect a minimum of approximately 700 mL for the second and third year of the study.

Rain Gauges. Eight rain gauges (nine in 1994) were randomly located on the property of Highland Feeders Limited. A small amount (7-10 mL) of canola cooking oil was poured in each rain gauge to prevent evaporation of water. Gauges were checked, and the volume of precipitation in each recorded on a regular basis and during rain events. When gauges reached a volume of 50-60 mm of precipitation they were emptied and the oil replaced.

Vacuum Pump Apparatus. Samples from a small runoff holding pond at Site 1 in 1994, and the large runoff holding pond were collected using a vacuum pump apparatus. The apparatus consisted of a vacuum pump attached to a 250 mL Erlenmeyer Vacuum Flask, for a trap, a 1L Erlenmeyer Vacuum Flask for sample collection, and approximately 4.6 m of plastic tubing fitted with a section of glass tubing on the end. The glass tubing was connected to the plastic tubing and the free end inserted into a hole in the centre of a rectangular piece of styrofoam, which acted as a floatation device and allowed the tube to be submerged. The plastic tubing was clamped onto a length of Flex Frame Aluminum rod, in two places, leaving 30-60 cm to be unattached. This unattached portion was that part of the tubing connected to the glass tubing supported by the styrofoam float.

A vacuum was applied to the system to collect a sample. A 1L non-sterile vacuum flask was rinsed three times with sterile water, then a sample was collected for analysis. Upon collection, the sample was transferred to a sterile 1L plastic bottle and kept on ice until analysis.

Chemical Analysis. Chemical analyses carried out on runoff samples were Ca, Cl, COD, K, Na, NH_3-N, pH, T-P, and TKN as presented in Dieken (1987).

Microbial Analysis. Samples were aseptically and serially diluted in phosphate buffer dilution bottles until the desired range was achieved. Spread plate analysis for heterotrophs and membrane filtration for faecal coliforms and faecal enterococci were performed as per the Microbiological Methods Manual (Coleman, 1990).

Percentage Dry Weight. Percentage dry weight was performed on all liquid samples from the runoff holding ponds, those collected by the automatic samplers and on soil samples collected during the irrigation study. Aluminum pans were dried at 100°C for four hours and placed in a desiccator until required. The weight of each pan was determined. Weights of the sample were determined. Samples were dried in an oven for 24 hours at $100^{o}C$, then allowed to cool in a desiccator and weight of the dried sample and pan were determined. Percentage Dry weight was calculated by dividing the dry weight by the wet weight and multiplying by 100. All dry weights were performed in triplicate for each sample and the mean percentage was calculated. For liquid samples from the runoff holding pond and the samplers, a volume of 20 mL, equal to approximately 20 grams wet weight, was generally used for each replicate, unless insufficient sample was available (as was the case during the 1994 sampling season). If sample volume was insufficient for 20 mL replicates, the volume was reduced so that three replicates of similar volume could be measured.

Runoff Analysis. The feedlot runoff data were evaluated by:

- analysis of rainfall event characteristics, e.g. return periods of storms
- calculation of yields from rainfall and runoff data
- statistical testing of yields
- correlation of yields with rainfall attributes.

Storm duration, average and maximum rainfall intensity and rainfall volumes were calculated for each storm event. The weather station data logger failed to record tipping bucket information for some 1996 events. From the runoff data, lag time for the runoff to start after the start of rainfall, the runoff duration, peak and average discharge rates and runoff volumes were calculated. Not all sites exhibited runoff for every storm event. Consequently, some minor storms have variable runoff data from site to site.

Return periods for storms were estimated by comparing the storm duration and average rainfall intensity with intensity-duration-frequency graphs based on 18 years of records from the Agriculture and Agri-Food Canada Research Station at Vegreville. Return periods for storms shorter than 30 minutes or longer than 24 hours were estimated by extrapolating the graphs.

Yields of runoff compared to rainfall were calculated as:

(11) $Y = (Q_v/P_v) * 100$

where:

yield (Y) is expressed as a percentage. The volumes of runoff (Q_v) and rainfall (P_v) were calculated from:

(12) $P_v = (\Sigma\, p \bullet t) \bullet A$

and

(13) $Q_v = (\Sigma\, q \bullet t) \bullet A$

where:

p = average rainfall intensity (mm ha^{-1}) over a 5 or 15 minute time interval

q = average discharge (m^3s^{-1}) over a 5 or 15 minute time interval

t = time interval, 5 or 15 minutes in which rainfall and runoff were recorded

A = is the watershed area (m^2) for a block of pens.

Feedlot

Highland Feeders Limited operates a new modern feedlot in the County of Two Hills, Alberta and is located approximately 25 kilometres north of Vegreville and the Alberta Research Council-Vegreville site.

Highland Feeders Ltd. feedlot is located on a half-section, NW27-14-54-W4 and SW34-14-54-W4, in the Whitford Plain District in the County of Two Hills. This area is characterized by undulating ground moraine. The half-section that the feedlot is on slopes north to south. The highest point has an elevation of 678 metres and the lowest point has an elevation of 640 metres. The average slope is 2.5% NE to SW over a horizontal distance of 1,493 metres.

The feedlot was recently constructed with a well planned drainage system. The pen areas are discrete watersheds, defined by the feed bunks at the outside of each block of pens. Pens were constructed at different times, presenting the opportunity to observe how soil and runoff characteristics different with pen age.

The climate at the site is continental, characterized by long cold winters and warm summers. January, the coldest month, has a mean temperature of -18^{o}C, and July, the warmest month, has a mean temperature of 17^{o}C. The yearly variation of temperature was observed as a winter low of -50^{o}C to a summer high of 38^{o}C. Annual total precipitation (long-term mean) is 450 mm, of which 125 mm occurs as snowfall. About 60% of the precipitation occurs during May to August. June, July and August have the highest monthly rainfall, with totals amounting to 200-230 mm. The balance of the yearly precipitation occurs as snowfall, (Dzikowski and Heywood, 1990). Rainfall may result from frontal system giving a general rain or short, intense localized summer storms. These events may occur during prolonged wet spells, or after prolonged dry spells.

Near surface bedrock of the area is the Belly River Formation of the Late Cretaceous era. The composition of the formation is nonmarine gray to greenish-gray, thick-bedded feldspathic sandstone, gray clayey siltstone, gray and green mudstone and concretionary ironstone. It is overlain by 1 to 30 metres of till, Macyk, *et al.*, (1985).

Surface soils at the site are of the Angus Ridge and Norma soil associations. Soil samples from the feedlot were classified, by hydrometer, as SCL, SC and L. Sand, silt and clay contents ranged between 50.2-53.2%, 20.0-29.0% and 20.8-24.8% respectively.

In the past 10 years the feedlot has grown from 2,300 head in 1988 to 12,000 head in 1991 to 25,000 head in 1997. The feedlot is oriented north-south with a ring road and a series of north-south roads for pen access. Feedlot pens average 75m x 75m, with concrete bunks and aprons, and five bar steel fence construction with attached windbreaks. The concrete feedbunk and apron is at the front of the pen. A waterer on a concrete apron is situated in the centre third of the pen. Pens are placed back to back, separated by a 20 m space that includes two cattle moving alleys and a drainage alley. Animal numbers per pen ranges from 100 head to 300 head per pen at an average density of 17.25 m^2 per animal. Pens slope from the feedbunk to the drain at 2.5%. Pens constructed early in the development of the feedlot were sloped at 1.5% to 2% from the feedbunk to the drain. The drain slopes 1.5% to 3.6% to a holding pond. The holding pond, to contain runoff from the pen area, is located at the extreme south end of the feedlot property and has a capacity of 160,000 m^3.

The feedlot consisted of five groups of pens covering 433,344 m^2. Pen areas were divided by farm roads that parallel the feed bunks and also the north/south outside perimeters of the pen areas. Each pen area includes two strings of pens that back onto a central drain flanked on both sides by travel alleys. Each central ditch drains south at a slope of one percent to a 160,000 m^3 evaporation pond. Each pen had a slope of 2.5 percent to the central ditch at the back of the pen. The evaporation pond was emptied annually by a side-roll irrigation system on an adjoining field.

There are currently four sets of back to back pens that drain to the holding pond. Water flows south along pen drains, and under a roadway through metal culverts. Each set of pens comprises one drainage area, defined by concrete feedbunks on both the east and west sides and bounded by an above grade road on the north and south sides. Figure 2 (Appendix II) shows the drainage area, layout and size of each of the pen groups. Total drainage area from feedlot pens was 433,344 m^2. The various drainage areas and pen data are outlined in Tables 3 and 4 (Appendix I).

Pen surfaces were prepared by removing topsoil from the area and cutting and filling to achieve the desired elevations and slopes. Soil packing was by the action of earthmoving equipment driving on the soil and/ or the use of packers.

Water is supplied to the feedlot by eight wells. These wells run continuously into two fresh water dugouts. From these wells, water is pumped to energy free waterers in each pen. Winter water consumption is 18 litres/head/day; summer consumption is 32 to 45 litres/head/day. Two factors can explain the apparent difference in water consumption; smaller animals go into the feedlot in late fall and require less water, the cool winter reduces water consumption and animals in the feedlot during the summer are considerably larger.

Highland Feeders Ltd. produces its own ration, which is based on cereal silage produced on 1,740 ha of land and purchased barley and supplements. Cattle starting on feed are fed a ration that is 75% silage and 25% barley (by dry weight) plus supplements. Finishing cattle are fed a ration that is 25% silage and 75% barley (by dry weight) plus supplement. Rations are delivered to each pen by a truck-mounted mixer.

RESULTS AND DISCUSSION

General Discussion

All raw data is compiled in a companion volume (Volume 2, Kennedy *et al.* 1997) to this report. The data reported in this report (Volume 1) is abridged from the companion volume.

The Results and Discussion section will primarily discuss the year-to-year observations from and analytical group perspectives, that is, the seven groups are: general discussion, hydrology, infiltration through feedlot floor, feedlot floor soil profile, chemistry of site runoff and storage pit, microbacteria of site runoff and storage pit, soil irrigation and microbial persistence.

Pen surface management at Highland Feeders Ltd. takes place on an ongoing basis. The first stage is the regular scrapping and mounding of manure in the pen. The second stage is the removal of the mounds and accumulated bedding and manure, and the land application of the manure. The objective is to have a clean, well drained pen surface to reduce 'tag' or manure on the animal and based on season various activities take place (see Table 5: Appendix I).

Pre-Project (1993). During 1993, pre-project instrumentation was installed at three locations in the feedlot. Stilling wells, Stevenson Water level recorders, evaporation pan, rain gauge, temperature and relative humidity probe and V-notch weirs were installed. Site 1, at this time, had a holding pond, during 1995 this was filled in and a culvert and V-notch installed to measure water volume. Sites 2 and 3 had V-notch weirs. Water samples for chemistry and microbiological analysis were not collected. Two rainfall events, one on August 25-26 and the other on September 12, with return periods $\geq$ 10 years were recorded.

Hydrology

Over the course of the study, two types of storm events were observed:

1. The first type of storm was typical of prairie thunderstorms, which was a very intense, short duration event that creates an immediate, low volume runoff event.

2. The second type of storm was a frontal storm, which typically was a long duration, low intensity storm producing a significant, though time delayed runoff event.

1994 Season. At the beginning of the 1994 season two ISCO 3700 portable samplers were installed at the flow measuring points at sites 2 and 3. Intakes for the samplers were placed inside the culverts behind the V-notch weirs. Samplers were activated to collect runoff by liquid level switches placed at the weirs.

In total, there were six runoff events recorded at Site 2 and seven at Site 3. Five of these storm events had return periods >50 years, the rest had return periods of <5 years. Total rainfall between May 24 and September 28, 1994 was 250.9 mm. Net evaporation during this time was 125.9 mm. Total evaporation was 273.8 mm.

Samples of runoff and liquid in the runoff holding pond were collected and analysed for chemical and microbiological parameters. Chemistry of the wastewater from all sources for the 1994 season are summarized in Table 6 (Appendix I) and microbiological data are summarized in Table 7 (Appendix I).

At the end of the 1994 season (October 11- 26, 1994), the wastewater holding pond was emptied by irrigation and the effluent spread on silage stubble.

Runoff yields ranged from 1.8% to 50.4% for the recorded events at sites 2 and 3. The average yield from Site 2 was 31.7% and Site 3 was 30.1%.

1995 Season. Site 4 was constructed in 1995. As part of the construction process the small runoff holding pond at the south end of Site 1 was drained and filled. A culvert, V-notch weir was installed to measure runoff from Site 1. Two additional ISCO 3700 samplers were acquired for installation at Sites 1 and 4. This installation took place in July and August. The first runoff sample from Site 4 occurred on August 14, 1995.

At the beginning of the 1995 season float operated potentiometers were installed to measure flow at the V-notch weirs. Potentiometer resistance varied with water depth at the weir and the values were averaged and stored at 5-minute intervals on Campbell Scientific CR10 and 21X Data loggers.

1995 was a drier than normal year with 124.5 mm of rain between June 22 and September 11. Normal rainfall for the area, during growing season is 200-230 mm (Dzikowski and Heywood, 1990). Net evaporation at the site during this time period was 171.9 mm; total evaporation was 296.4 mm.

In total there were eight runoff events recorded during 1995. Four events were recorded at Site 2, three at Site 3 and one at Site 4. Runoff yield ranged from 9.1 % to 53.9%. The yield of 53.9% occurred at Site 4, on the new pen surface before any cattle had been on it. For the same event Site 3, which was occupied by cattle had a yield of 40.3%. Chemistry data from the four sites are summarized in Table 8 (Appendix I). Microbiological data are summarized in Table 9 (Appendix I).

1996 Season. During May 22 to September 20, 1996, 406 mm of rain was recorded. The first recorded rainfall event was April 24, 1996. A data logger malfunction resulted in lost data between June 9 and July 3, 1996. Rainfall, etc. was not available from a tipping bucket rain gauge after July 5, 1996. Rainfall records were kept manually. Characteristic of this year was its coolness and higher than normal relative humidity. Storms recorded in 1996 tended to be long duration, low intensity. Chemistry data for 1996 are summarized in Table 10 (Appendix 1). Microbiological data are summarized in Table 11 (Appendix 1).

Five rainfall events with runoff were recorded in 1993 from August to freeze-up. 1994 was a high runoff year with 15 rainfall events with runoff. 1995 and 1996 were low runoff years with only three rainfall events with runoff for each year. The automated weather station data logger did not record rainfall in the month of July, 1996, limiting the analysis to two storms.

Runoff did not occur for every pen area with every storm. Tables 22-24 (Appendix I) classify rainfall events with pen areas that had runoff.

Of note was the frequency and duration of rainfall events in 1994 and consequently the frequency and size of runoff events. 1995 and 1996 in contrast had much lower runoff even though some of the storms were significant (return periods greater than 50 years).

In 1993, Pen Area 3 was newly constructed and was a well graded, compacted bare earth lot. In 1995, Pen Area 4 was newly constructed and runoff events should share characteristics similar to Pen Area 3 in 1993. The variation of runoff, as soil and infiltration characteristics changed with cattle occupancy, have not been examined in the hydrology data. The infiltration studies found important changes that explain the relationship between rainfall and runoff observed.

Cattle numbers by pen area varied throughout the study but the effect of the number of occupied pens by pen area on runoff characteristics has not been analyzed.

The selected hydrographs (Fig. 19, Appendix II) show multiple peaks in the runoff that mimic the rainfall peaks. Typically, runoff commenced approximately 24 hours after initiation of rainfall. The Site 3, Sept. 1993 hydrograph shows the response of a newly constructed pen area before cattle had been moved in. Lag times were shorter for this event. The August 1994 event for this same site shows a runoff response similar to other sites, indicating how quickly the pen area's detention storage developed once cattle were in the new pens.

No snowmelt events were recorded. The feedlot pens were cleaned just before snowmelt and the combined snow and manure was stored just above the catch basin. The manure piles were spread later in the summer.

The storm events ranged in duration and depth from 5 to 52 hours and 85 mm to 190 mm. These events were in the range of return periods of 1:2 to greater than 1:50 years for the Vegreville area. The USDA SCS rainfall-runoff model was used to estimate the runoff volumes that actually occurred for these storms. The SCS Curve Numbers ranged between 55 and 83 in contrast to the recommended design SCS Curve Number of 91 used for estimating runoff from unpaved feedlots for average moisture conditions (Westerman and Overcash, 1980).

Watts and McKay (1986) reported that a number of studies typically describe a soil/manure interface that develops a characteristic formation virtually regardless of the original soil type. The interface is compacted by the cattle's hooves and remains at a nearly constant moisture content. This compacted layer acts as a barrier to water movement. Infiltration tests (Kennedy *et al.*, 1995) match the observations from Australian and USA studies. The high SARs in the layer also will tend to disperse the soil in the layer and further reduce the infiltration capacity. Watts and McKay (1986) concluded that there is little or no infiltration through this layer and the manure acts like a sponge on top of an impermeable membrane.

The infiltration test results (Kennedy *et al.*, 1995) are consistent with this model. The runoff characteristics from the hydrographs also are consistent. The semi-arid climate at this central Alberta site dries the manure pack and provides a reservoir to store significant amounts of rainfall. Because long duration rains tend to produce volumes that could fill pen surface storage, runoff yields increase with long duration storms (1 day or greater). The storage in the manure layer is increased through the storm event as the cattle create micro-depressions that hold runoff. Once the manure layer is saturated, the runoff begins and with a significant portion of the rain flowing as runoff, the runoff peaks mimic rainfall peaks throughout the storm event. The percent of rain yielding runoff increases for larger volume storms because once the manure layer storage is filled, rain is substantially diverted to surface runoff.

The infiltration and the hydrology results confirm that feedlot pen soils have runoff and erosion characteristics similar to the characteristics observed by soil scientists and hydrologists in Alberta's Luvisolic and Solonetzic soils. Wright and Vanderwel (1995) observed that these soils have the highest runoff and erosion potential of Alberta's soils. Consequently, so should feedlot pen soils. However, the manure layer and the micro-depressions created by the cattle's hooves provide much more moisture storage than a conventional Solonetzic soil's "A" horizon. The conceptual model for a feedlot pen soil is a Solonetzic soil covered with a 10 cm layer of peat. In Alberta's semi-arid climate, the manure layer provides a large storage reservoir for most storms. More rainfall is required to saturate a feedlot pen soil than conventional soils. However, once the manure is saturated, the hardpan directs all the rain to runoff so that runoff yields increase with a sequence of storms or a long duration storm. With saturation, feedlot pen soils mimic Luvisols and Solonetzs with high runoff and high erosion of surface materials (manure). With well graded pens and ditches being the convention for modern feedlots, a major runoff event will transport more manure from the pens as the runoff continues, not less. Designers should consider sedimentation areas upstream of the catch basin or be prepared to suggest management techniques to deal with heavier loads of manure in the catch basin.

While catch basin design criteria typically is based on single storm events (originally 1:10 year 24 hour storms in Australia, 1:25 year 24 hour storms for USA and Alberta), Watts and McKay (1986) point out that such criteria may increase the chances of catastrophic failure more frequently than the design storm return frequency. They observe that since feedlot ponds typically are emptied only once a year, their risks of overflowing are related to cumulative runoff events rather than a single large storm filling an empty basin. Watts and McKay (1986) recommended that cumulative runoff through the year should be the sizing criteria rather than a single storm event.

The runoff yields, mean of 33%, from individual storms (with return periods greater than 1:10 years) have been less than the yield of 42% estimated from Alberta Code of Practice

(Intensive Livestock Operations Committee, 1995). However, to conclude that the Code of Practice over-estimates storage is pre-mature in light of the comments made by Watts and McKay (1986). Lott (1994) suggested catch basins' "active volume", the volume required to store runoff to prevent spills, be "a function of the runoff yield from the wettest year in 10".

The Australian modeling of catastrophic failure of feedlot catch basins relates catch basin design to management. At Highland Feeders, the catch basin is used as an irrigation reservoir for a side-roll irrigation system. The catch basin is drawn down continuously through the summer. However, conventionally, most feedlots empty the catch basin when it is full. In a wet summer, even a small storm, following a series of storms, could provide the runoff that could overtop the catch basin. With one time emptying of a catch basin, focussing on the 1:10 wettest year to design capacity may be more appropriate than designing capacity for the 1:25 year 24 hour storm.

Infiltration Studies On Feedlot Pen Surfaces

Observations. The purpose of the infiltration study was to test the technique of infiltrometer (Kennedy *et al.*, 1995) use and to gather preliminary information about infiltration through a feedlot pen surface. Three sites in the feedlot were chosen: (1) a new pen section under construction in 1995, (2) a pen area with manure pack in place, and (3) a pen area with the manure pack and black organic layer removed. In addition, an infiltration test was run in the pen drainage channel at the south of end of the pens in Site 1.

Test Site 1. Pens at Test Site 1 were constructed in 1995 and required 0.5 to 3 metres of fill to develop the desired pen slope. Soil was hauled to the site, placed and formed with a road grader. Packing of the soil was by the action of the heavy equipment driving on the fill as part of the placement procedure. Soil at the site is a sandy clay loam to a sandy loam. Infiltration tests were conducted immediately after the soil had been placed and graded and prior to cattle being placed in the pen.

The first test lasted two hours and gave a final infiltration rate of 7.44 X 10^{-4} cms^{-1} and 3.71 x 10^{-4} cms^{-1} (see Table 15, Appendix I). Two hours was not a long enough time to reach a final, stable infiltration rate. Another set of readings was taken. Prior to this set of readings, 67 mm of precipitation had fallen in the previous six-day period. The soil surface was dry, however 1-2 mm beneath the surface the soil was at or near field capacity. The final infiltration rate of this test was 2.86 x 10^{-6} cms^{-1} and 2.33 x 10^{-6} cms^{-1} after 12,970 minutes (216 hours).

Test Site 2. Pen 60, a three-year-old pen, with an intact manure pack was the site of the next test. Infiltrometers were set up within a few hours of the cattle being moved out.

A 6 cm moist, black layer was identified beneath the manure pack and above the soil manure interface. *In situ*, the layer exhibited high resistance to penetration. In a drier state this layer resembled charcoal in texture, strength, colour and staining ability. In a moist state it had a felt-like texture. In a wet state it was grease like--smearing and slippery. Fly maggots were observed on the upper surface of this layer, but not in the layer or below it, indicating that the layer was probably anaerobic. Organic matter content of the layer was 6.0% as compared to 23.3% in the manure pack and 1.5% in the soil below it. An interesting note, chloride content of the layer was 2,540 ppm, compared to 5,600 in the manure pack. Three infiltrometer readings were taken. Final infiltration was 0 cms^{-1}, however time to achieve this rate varied from 30 minutes to 8,220 minutes (137 hours) (Table 16, Appendix I). Figure 3 (Appendix II) shows a profile of a pen manure surface and manure pack.

Test Site 3. After the manure pack and the black organic layer had been removed, infiltration was again measured in Pen 60. A mixed later of soil interspersed with pockets of organic material and ash-like material was found below the impervious organic layer. A layer of organic/mineral mix approximately 150 mm thick, was observed. This layer was probably formed by the action of cattle hooves mixing soil and manure over time. Two infiltration readings were taken on this layer. After 11,546 minutes (192 hours) infiltration readings were 1.8 X 10^{-7} cms^{-1} and 7.8 X 10^{-8} cms^{-1}, and after 20,186 minutes (336 hours) infiltration readings were 0 cms^{-1} (Table 17, Appendix I).

Test Site 4. A fourth infiltration test was conducted in the water run between pens in Site 1 and the instrumented culvert. A layer of organic matter and sediment had been carried from the pens, by the runoff and deposited in the area at the south end of the pen section. Infiltrometer rings were placed on this sedimentary area. Over a thirty-day period there was no measurable infiltration through this layer of organic sediment from the pens. The material was made up of faecal materials, grain hulls, chopped straw, hair and other water born materials from the pen surfaces (Table 18, Appendix II).

Feedlot Floor Soil Profile. Complete soil, chemical and tracer data are reported in Table 19 (Appendix I).

Sites 1, 2, 3 showed no significant difference in mean NO_3-N levels down to a depth of 1.0 m although pen 43 in Site 2 (2 years of cattle occupancy) had elevated NO_3-N levels from the 20 to 80 cm depth.

Chloride levels were found to be significantly elevated in the upper parts of the soil profile in pens of Site 1 and Site 2 and declined with depth when compared to Site 3. Compared to Site 2, Site 1, which has been in operation longer, contained higher levels of Cl at the near surface, and Cl concentrations declined deeper in the profile (means for Sites 1, 2, 3 in Table 19 (Appendix I).

Site 3 basically represents the background levels of NO_3-N and Cl in the cut and fill materials used in landscaping.

Since at least a small amount of water is known to infiltrate in the feedlot pens and this water is known to contain nitrogen (runoff sample) this study would indicate NO_3-N as an unreliable tracer for infiltration studies of feedlots. No gradient of NO_3-N concentration was found in Sites 1 or 2 that varied significantly from Site 3. A possible explanation is that any nitrogen leached into the soil profile is denitrified and escapes the soil profile as N_2 gas. Nelson and Terry (1996) found that irrigation that caused anaerobic conditions caused denitrification. This is highly probable in this situation since the soil surface appeared to be a moist and sealed by an impervious mat. Soil cores were gleyed also indicating an anaerobic soil condition. This is the explanation given by Montgomery *et al.* (1997) in their research. Mielke and Mazurak (1976) also reported the lack of nitrate in the profile below feedlots but attributed it to the lack of infiltration.

The greater concentration of Cl found in pens of Site 1 reflect the longer period of utilization and consequently longer period of water containing Cl infiltrating the pen surface. The presence of elevated Cl down into the profile confirms water movement did occur from the surface into the profile. Since water infiltration would be accumulatively greater in the 5-year-old pens than in the pens utilized for 2 years (Site 2), the greater amount of Cl in Site 1 shows that some infiltration does occur in feedlot pens but to a limited extent since the Cl concentration was not significantly greater below 20 cm even after 5 yrs.

An elevated Cl concentration at Site 3 indicates that during initial utilization of a pen (in this case one week) a relatively quick Cl build-up in the 0-10 cm soil depth occurred.

Chemistry of Site Runoff and Storage Pit Contents

Chemical data was collected for three years at Sites 2, and 3 and two years at Sites 1 and 4. Chemical data from Site 3 (1995) were taken in the first year of animal occupancy. Chemical data were collected for two years from the runoff holding pond.

Ca. On occupied pens, average Ca was 67.3 – 91.7 mgL^{-1} in the runoff. Variability, as measured by standard deviation, tended to increase as years of pen use decreased. Two Sites (Sites 2 and 4) showed extreme variability in 1996. Site 2 was, in its forth year of operation and Site 4 was in its second year of operation. Site 1, which started operation in 1988, showed very consistent readings in all three years (1994, 1995, 1996). This information is shown in Figure 10 (Appendix II).

Readings in the wastewater storage were slightly higher in 1995 (129.9 mgL^{-1} as compared to 1996, 96.8 mgL^{-1}). This may be a dilution effect due to the dry conditions in 1995.

Cl. Chloride ranged from a high of 1387.8 mgL^{-1} to a low of 232.5 mgL^{-1}. The high content occurred on Site 1 in 1994 prior to the feedlot removing salt from the cattle ration. At this Site the high reading was 1387.8 mgL^{-1}, the low 68.3 mgL^{-1} with an average of 964.1 mgL^{-1}. As indicated by a standard deviation of 1387.8 mgL^{-1} there was a large variability among readings. In subsequent years, a high of 925.2 mgL^{-1} to a low of 503.9 mgL^{-1} occurred in occupied pens. The lowest reading was 154.6 mgL^{-1} (range 0.8 – 728.0 mgL^{-1}) on Site 4 in 1995 before it was occupied by cattle. This indicates a naturally occurring level of Cl on the soils of this area. Figure 11 (Appendix II) provides a graph of these data.

In the wastewater storage the level of Cl ranged from 616.4 mgL^{-1} in 1993 to 466.7 mgL^{-1} in 1996. This lower level in 1996 was likely due to both dilution effects of a wetter year and the fact that salt had been removed from cattle rations. Part of this dilution is due to rainfall directly into the storage, and part is due to the dilution effects of runoff from roadways entering this wastewater storage.

Variability in runoff samples (522.3 mgL^{-1} – 232.5 mgL^{-1}) as indicted by standard deviation was greater than the variability in the wastewater storage (166.8 mgL^{-1} – 70.7 mgL^{-1}).

COD. Over three years, values in runoff ranged from a high of 25,244 mgL^{-1} to a low of 61 mgL^{-1}. The low was from Site 4, prior to cattle being placed on it. In the wastewater storage COD ranged from a low of 117 mgL^{-1} to a high of 2424 mgL^{-1}. The wastewater storage was newly constructed in 1995 and in the initial stages of filling was very clean, becoming a brown color later on in the season. The lower COD in the wastewater storage was likely caused by dilution of rainwater falling on the surface, and runoff from roadways – and some natural processes (wind blowing on the liquid surface). This information is shown in Figure 12 (Appendix II).

K. Potassium in runoff ranged from a low of 16.5 mgL^{-1} to a high of 113.4 mgL^{-1}. from Sites 1, 2, and 3. Site 4 had a low of 4.0 mgL^{-1} to a high of 476.0 mgL^{-1} in 1995. This can be explained by the fact that this was a new site with no cattle on it for most of the season. In 1996 the range for Site 4 was 10 to 684 mgL^{-1}. Sites 1 and 2 had readings ranging from 56.1 to 1134.0 mgL^{-1} with an average of 586.6 mgL^{-1} as compared to Site 3 readings from 16.5 to 1100.0 mgL^{-1} with an average of 418.4 mgL^{-1}. The likely explanation is an age effect. Sites 1 and 2 have had more years of use. In examining variability, as represented by standard deviation, the oldest site, Site 1 in use for eight years, had the least variability. This indicates a time effect and a stability in readings from a more mature site. This information is shown in Figure 13 (Appendix II).

Na. Sodium in a feedlot comes from two sources: naturally occurring in feed and water and introduced. The introduced sodium is added to the feed in the form of NaCl at levels of up to 0.5%, by dry matter weight. Water at Highland Feeders has a relatively high level (469 mgL^{-1}).

Sodium in wastewater runoff ranged from 8.0 mgL^{-1} (Site 4, 1995) to 3850 mgL^{-1}. In 1994, Sites 1, 2, and 3 had average readings of 510, 375, and 332.8 mg/l respectively. In the fall of 1994, wastewater was irrigated onto cropland. Soil tests of the spreading area indicated an increase in Na levels and management of the feedlot removed all added NaCl from cattle rations, relying on naturally occurring Na in water and foodstuffs to maintain cattle health. In 1995, all sites showed a notable drop in Na in the runoff water. In 1996 slightly higher levels of Na were found at Sites 2 and 3 while Site 1 (the oldest) showed a slight reduction. Site 4 showed a substantial increase from an average of 83.8 mgL^{-1} to 238.5 mgL^{-1} which comes from the addition of cattle to a new site. This information is shown in Figure 14 (Appendix II).

TKN. Total Kjehdal nitrogen is a measure of total nitrogen in the sample. [Suggest this be moved to end – Glossary of Terms] This ranged from a low of 4.2 mgL^{-1} from Site 4, before cattle, to a high of 2450 mgL^{-1}, again from Site 4, in the first year of use for cattle housing. On the remaining sites, values ranged from 6.5 mgL^{-1} to 1352 mgL^{-1}. In the wastewater storage, levels ranged from 140.0 to 285.0 mgL^{-1}. As a site aged, variability in the readings decreased, indicating an age effect. TKN readings from the wastewater storage were lower than on the runoff, indicating both dilution and denitrification by natural processes. Variability in the TKN readings from the wastewater storage pack was low as compared to variability in the runoff water. This information is shown in Figure 15 (Appendix II).

NH_3-N. Ammonia-nitrogen is a measure of the readily available nitrogen in the wastewater runoff. [Suggest move to Glossary] This nitrogen is nitrified by natural processes and released to the atmosphere as nitrogen gas, or is available to plants when spread on cropland. Levels of NH_3-N ranged from 0.8 mgL^{-1} (from Site 4 before cattle) to 850 mgL^{-1} from Site 4, in the first year of use. There is an age-related trend to less variability in the range of observed levels of NH_3-N in the runoff as the site ages. In this case, Site 1, in use for eight years, showed less variability in NH_3-N readings as compared to Site 4, which was just put into use. This information is shown in Figure 16 (Appendix II).

pH. pH values in the runoff ranged from 6.4 to 8.9, with an average of 7.6. In the wastewater storage, pH ranged from 7.5 to 8.0 with an average of 7.7. This information is shown in Figure 17 (Appendix II).

T-P. Total phosphorus ranged from 1.0 to 395 mgL^{-1}. Both of these values were from Site 4, the low value in the time period before cattle were placed in the pens and the high value in the first year of operation. From Sites 1, 2, and 3, the low was 1.1 mgL^{-1} and the high 294.0 mgL^{-1}. Variability in T-P levels, as indicated by standard deviation relative to average, decreased as the age of the site increased. The oldest pens (Site 1) had the least variability, and the youngest pens (Site 4) had the most variability.

Total phosphorus levels in the wastewater storage ranged between 12.6 mgL^{-1} and 53.0 mgL^{-1} with a low variability. This indicates a relatively consistent value with time. Again values of T-P were lower in the runoff storage than in the raw runoff, indicating dilution from rain and road runoff. This information is shown in Figure 18 (Appendix II).

From the point of view of a feedlot operation, the important levels of the plant nutrients and chemicals in the runoff are those in the wastewater runoff storage. These values tend to be lower in storage than in the raw runoff due to natural processes and dilution.

Trends

1. The range of values for all parameters was narrower in the runoff storage pond as compared to the raw runoff water. This indicates buffering, natural processes and dilution.

2. An age trend was also apparent. Older feedlot pens showed less variability in the range of quantity of K, TKN, NH_4N, and T-P as compared to newer sites. This indicates a series of natural processes taking place in the feedlot floor that affect the availability of nutrients to runoff water.

Individual Runoff Events. On August 7-10, 1995 a runoff event caused by 145.3 mm of rain over 59.5 hours occurred. Runoff volumes were 40.3% and 53.9% from Sites 2 and 4. During this event all readings at Site 1 (seven years of use) tended to increase as the runoff event progressed. At Site 2 (three years of use) and Site 3 (one year of use) the same trend was apparent, though with more variability in the readings. Values of Ca, Cl, COD, NH_3-N, and T-P had increased readings during the event, however, intermediate readings were higher than final readings. Values of Ca, Na, K, Cl, COD, TKN, NH_3-N, T-P at Site 4, which had not had cattle on it tended to be very variable, though ending values were higher than beginning values. All values peaked during the event at Site 4, then decreased for the last reading.

On July 10-11, 1996 a runoff event occurred caused by 43.2 mm of rain. Values of Na, K, Cl, COD, TKN, NH_3-N, T-P from Sites 2, 3, and 4 tended to increase during the event. At Site 1 (the oldest site) ending values were lower than beginning values.

Concentrations of Ca, Na, K, Cl, COD, TKN, NH_3-N, and T-P tend to vary with rainfall event intensity, duration, time, depth of rain and age of the feedlot floor. Older feedlot floors tended to show less variability in concentrations. What is apparent is the variability in concentration between rainfall events.

Microbiology of Site Runoff and Storage Pit Contents

Three types of microorganisms were monitored: heterotrophs, faecal enterococci, and faecal coliforms. Runoff samples were collected automatically throughout a runoff event and then incubated to determine numbers of microbes in the runoff. Samples of the runoff water in the storage pond were collected and analyzed on a regular basis.

Over the course of three years the average levels of heterotrophic plate counts (HPC) varied between 1.5×10^7 to 1.7×10^8 CFU for Sites 1, 2, and 3. In the first year of existence for site 4 (1995) and before cattle were placed on it, HPC was about 10^6 CFU. The runoff storage pond had counts of 10^7 CFU.

Readings of faecal enterococci and faecal coliforms over the three years varied between 5.0×10^5 to 1.1×10^8 CFU for Sites 1, 2, and 3. Again Site 4 in 1995 was an order of magnitude lower, being at 10^5 to 10^7 CFU. Samples from the runoff storage pond had readings in the order of 10^5 to 10^7 CFU.

Lower readings in the storage pond, as compared to fresh runoff, can be explained by dilution effects and microorganism die off. What is surprising is the high numbers of microorganisms measured in the runoff from Site 4, prior to placing livestock on it in 1995.

This information is shown in Figures 20, 21, 22, Appendix II.

The contribution to the microbial load by the drinking water was minimal since all counts were very low (Table 9, Appendix I).

Soil Irrigation and Microbial Persistence. During 1994 and again during 1995 and 1996, collected runoff was spread on cropland using a side roll irrigation system. In 1994, 100 mm was applied October 9-10. In 1995 the same application was done August 28-29. Prior to application background levels of heterotrophs, faecal coliforms and faecal enterococci in the soil (surface 1 cm) were determined. After application of the material samples of soil were gathered over a period of days and incubated to determine microorganism die-off under field conditions

Microorganism die-off was not encountered for two weeks in 1994. This was probably due to cold weather conditions at the end of October causing microorganisms to remain dormant but viable (Table 12, Appendix I). Microorganisms died-off in 13 days in 1995 when irrigation took place in August. This die-off was likely an effect of warm weather and exposure to dehydration and sunlight (Table 13, Appendix I).

Microbial die-off was observed after 20 days in 1996, with a September irrigation, and this was most likely due to cool conditions forcing dormancy but maintaining viabilities (Table 14, Appendix I).

Feedlot Runoff Utilization

Runoff from the feedlot pens was collected in a holding pond at the south end of the feedlot pens. On an as necessary basis a side roll irrigation system was used to lower the level of the holding pond. The effluent was spread on a field south of, and adjacent to the holding pond. Spreading of the effluent took place in October 1994, in August 1995, and in September, 1996.

The 1994 irrigation rate and amount, 10 cm did not cause runoff. The field's surface was a loam to fine sandy loam soil with stubble and considerable second growth barley plants. The soil was relatively dry to 0.5m deep at the time of irrigation, being less than 50% of field capacity based on hand field measurement (Irrigation Scheduling, 1980).

Analysis of the effluent sampled in each year is presented in Table 20 (Appendix I).

The total nitrogen content in the effluent was similar in each of the three years although the amount as NH_4-N varied from 75% to 29%.

Although the chemical parameters measured in the effluent were similar in each year, the concentrations in 1996 were consistently lower than those found in the other two years.

The effluent was slightly basic with pH ranging from 7.5 - 8.0.

Three days after the irrigation the soil sampling to 45 cm revealed the wetting front from the irrigation was 15-30 cm deep in the soil profile.

Changes in soil did occur as a result of the irrigation as illustrated in the summary of soil analysis in Table 21 (Appendix I).

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Irrigation with effluent increased the level of NH_4-N in the soil as seen in Table 21 (Appendix I). When the N levels at various depths are compared over the sampling period; little nitrogen, including NO_3-N, appears to have moved below 15 cm. NO_3-N increased three-fold immediately after the irrigation and approximately six times by the following spring when compared to the before irrigation concentrations of 1994.

Available soil phosphorus in the surface 15 cm increased as a result of the effluent irrigation.

Potassium levels in the soil increase approximately 200% in the surface 15 cm and 50% in the 15-30 cm depth of the profile as a result of the effluent irrigation. No impact was observed in the 30-45 cm depth of the soil profile as a result of the effluent irrigation.

Sodium level increased approximately five-fold in the surface 15 cm and doubled in the 15-30 cm depth of the profile as a result of the irrigation with feedlot effluent.

The pH of the surface 30 cm increased slightly as a result of the effluent. The effluent was slightly basic (pH 7.5 - 8.0) and the high volume of irrigation applied contributed to the ability of this effluent to impact on soil pH.

The slightly lower concentrations of selected chemicals found in the effluent in 1996 compared to 1994 and 1995 likely reflects a dilution effect and a greater quantity of runoff experienced in 1996.

The variation in the relative portion of NH_4-N compared to the total-N found in the effluent could be the result of differing microbial activity in the feedlot pens and in the lagoon in the different years. Regretfully, the analysis did not distinguish the portions of NO_3-N or organic-N in the total-N so further explanation of varying nitrogen portions is speculative.

The feedlot effluent concentrations of N and K are about one-tenth the concentration found in liquid, hog manure. Phosphorus concentration was approximately one-hundredth that found in liquid hog manure (Intensive Livestock Operations Committee, 1995).

The increase in the level of NH_4-N as a result of the effluent irrigation is expected because of the concentrations of NH_4-N in the effluent. The decline in NH_4-N and the increase in NO_3-N from fall 1994 to spring 1995 suggest the microbial conversion of NH_4-N to NO_3-N rather than the NH_3 gasing-off.

Ten centimetres of effluent contains enough phosphorus to increase the available phosphate in the soil. The depth to which the effluent P moved down in to the soil profile (<15 cm) is surprising as the wide dispersal of the effluent within the soil profile would subject the P to being quickly bound up in the soil. The elevated level of available PO_4-P also found the following spring may indicate some enhanced solubility of effluent phosphorus compared to conventional fertilizer phosphorus. This is similar to Robinson and Sharpley (1996) findings with leachate from poultry manure.

The effluent contained considerable amounts of potassium and this loading is reflected in the increase in soil K observed. Normally K is considered less mobile in the soil than NO_3-N but with this application of K, the K apparently moved to an equal or greater depth in the soil profile than did the NO_3-N. This is likely a reflection of the total surface loading of K being much higher than the loading rate of nitrogen.

The addition of potassium, calcium and sodium provided in the effluent would all contribute to the increase in salinity found in the soil after the irrigation. Although the salt levels were elevated by the effluent, a critical EC of 4 ms cm^{-1} was not reached with the single irrigation of 10 cm. A longer term with repeated irrigation is needed to evaluate the salt accumulation and leaching under specific soil and rainfall conditions.

CONCLUSIONS

From this Study

1. Soil nutrient fertility (N,P,K) can be increased by irrigating with runoff from a feedlot. The 10 cm of irrigation effluent supplied approximately one-half of the N, one-third of the P and twice the K removed from a field in a 3,360 $kgha^{-1}$ crop of barley. A combination of effluent sampling and soil sampling would enable effluent irrigation to be a manageable part of a crop fertility program.

2. Specific care in monitoring K is needed on land repeatedly irrigated with feedlot effluent since this nutrient can be supplied in excess of the annual crop uptake by a single application of 10 cm of irrigation with effluent.

3. Repeated irrigation of effluents on the same land area requires careful monitoring of total salt loading to insure that critical levels are not exceeded.

4. The final fate of microorganisms must be considered throughout the spring, summer and fall seasons in future studies.

5. Soil pH should be monitored if repeated applications of effluent are undertaken, as the effluent had the capacity to alter pH at this site.

6. Utilization of specific chemical tracers can be utilized to evaluate whether or not infiltration takes place under feedlot pens. Chloride appears a more reliable tracer than NO_3-N in evaluating the movement of water in the soil profile under a feedlot.

7. This limited study indicates NO_3-N leaching through a soil profile under a feedlot pen does not pose a high risk of ground water contamination with loam soil or soil with a lower hydraulic conductivity than under the feedlot in this study.

8. Feedlot pens with active use have hardpans that severely restrict infiltration of water below the manure layer. The manure layer has substantial storage capacity that combined with Alberta's semi-arid climate usually means that individual storms have a significant moisture reservoir to fill before runoff begins. Antecedent moisture in the manure layer is the determining factor for predicting a runoff event. However, the hardpan layer also results in characteristics similar to Alberta's Luvisolic and Solonetzic soils, which have high runoff and erosion potential. Consequently, when runoff does commence, erosion of manure and runoff yields increase with longer storms.

9. Sedimentation basins are required as part of the feedlot drainage system to facilitate the collection and removal of sediment transported by erosion during runoff events.

10. Sizing criteria for catch basins has focussed on severe single event storms. In light of the runoff characteristics of feedlot pen soils and the annual one-time emptying of catch basins, runoff yields from a critical wet year may be an alternative design criteria more appropriate to current management.

11. The three and half year record of rain and runoff at Highland Feeders with both wet and dry years and large and small storms makes evaluation of these alternate criteria a possibility. Focussing on a comparison of wet years versus normal years justifies continuing the monitoring to confirm with data what other researchers have been investigated by modeling.

12. The variability in this data indicates a need for more replication than undertaken in this study.